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A VALIDATION OF THE PROPOSED ROYAL AUSTRALIAN NAVY STANDARD WORK WEEK AND NAVAL MANAGEMENT DIARY USING A SIMULATED CREW OF AN ARMIDALE CLASS PATROL BOAT

by

Jessica Groot

December 2015

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LIST OF ACRONYMS AND ABBREVIATIONS

ACPB	Armidale Class Patrol Boat
AWD	air warfare destroyer
BAE	blood alcohol equivalent
CPO	Chief Petty Officer
DSTO	Defence Science Technology Organisation
FAST	Fatigue Avoidance Scheduling Tool
HADR	humanitarian assistance and disaster relief
HOTO	hand over take over
ICT	information communication technology
LHD	landing helicopter dock (ship class)
MOS	military occupation specialty
NAVMAC	Navy Manpower Analysis Centre
NGN	New Generation Navy
NMD	Navy Management Diary
NSManS	Navy strategic management system
NSWW	Navy Standard Work Week
OJT	on the job training
OPNAV	Office of the Chief of Naval Operations
PSG	polysomnography
PTSD	post-traumatic stress disorder
PVT	psychomotor vigilance test
RAN	Royal Australian Navy
SAD	ships army department
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness model
TWT	active work hours
TST	daily sleep duration
USCG	United States Coast Guard
WAM	wrist activity monitor

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I would like to acknowledge Dr. Nita L. Shattuck for her continuous help and guidance. It has been a journey that would not have been possible without you; not only did you teach me about the subject matter, but you taught me a lot about life. I will be forever grateful. My gratitude is extended to Dr. Panagiotis Matsangas, for his assistance for his guidance throughout this endeavor, and for his guidance with software. I acknowledge CAPT Mike Smith and CMDR Scott Hamilton, RAN, for their help and persistence and most of all, the information and data! Camille, from the Graduate Writing Center, you will forever be the diligent fox—Thank you.

Most of all, I would like to thank Ray and Abigail. My darling daughter, you have travelled across the world and carried on like a trooper. In the future, you will know the sacrifice we asked of you, and I hope you will know how grateful I am. Ray—there are no words to express my love and gratitude for the support you give me. Instead, I recall the words you chose from Sir Richard Francis Burton:

> ***"Despise not, gentle reader, first impressions… if a sharp, well defined outline is to be drawn, it must be done immediately after arrival at a place, when the sense of contrast is still fresh upon the mind, and before second and third have ousted first thoughts… The man who has dwelt a score of years in a place, has forgotten every feeling with which he first sighted it; and if he writes about it, he writes for himself and for his fellow-oldsters, not for the public. The sketcher who acts as I propose to do well, of course, make an occasional bad blunder…But, in the main, the gauche will be true and vivid."***

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I. INTRODUCTION

This thesis aims to investigate the impact of the possible introduction of the U.S. Navy Standard Work Week (NSWW) to the Royal Australian Navy (RAN), specifically on the small ship crew level. The thesis utilizes a simulation of a typical crew and associated activities and the impact of fatigue and degradation of performance while at sea. This investigation is framed using the RAN's cultural reform program, New Generation Navy (NGN); specifically, its people-focused policies.

In 2008, the Chief of the Royal Australian Navy (RAN) launched a significant reform program; the VADM Crane stated, "New Generation Navy is what I stand for. Navy must remain capable of defending this nation if called upon to do so. But we have to begin working smarter, not harder" (Kemp, 2008, p. 2). With these words, the RAN Chief announced his vision for the NGN program. Launching three areas of reform—leadership and values, cultural reform, and structural reform—the plan was established on the dawn of receiving the Hobart Class Air Warfare Destroyer (AWD) and the Canberra Class Landing Helicopter Dock (LHD) platforms. At the time of the launch, the Chief of Navy acknowledged that the program would be cultural as well as practical, "Changing old habits won't always be easy but New Generation Navy is here to stay" (Kemp, 2008, p. 2).

Positioned under the three reforms were the three pillars of the NGN: People, Performance, and Professionalism. The three pillars were the cornerstones of ten signature behaviors that were designed to give clear guidance on the behavior and performance of personnel within the Royal Australian Navy. The first pillar, People, related to individual behaviors, but also to how individuals interacted with others. The pillar's underlying value was to respect every member's contribution, and encouraged individuals to consider how they help others make a full contribution to the RAN through the three behaviors. The second pillar, Performance, was aimed at empowering individuals to take action to improve their workplace. The four behaviors outline specific actions such as being cost conscious, fixing problems, taking action, and challenging and innovating. The third pillar, Professionalism, directly related to the RAN's vision

statement: “An Australian Navy renowned for excellence in service to the nation” and the RANs motto: “Navy–Serving Australia with Pride.” The three signature behaviors under this pillar describe how individuals could best serve their country and abide by the RAN’s vision and motto. Behaviors for this pillar include “Be the best I can be,” and “make Navy proud, make Australia proud.”

The original NGN reforms set out key focus points. The cultural reform included “reducing the increasing expectation that operational reliefs are an acceptable method of crewing ships at no notice.” Within the structural reform, there was to be a shift away from relying on training at sea: in order to unblock training pipelines, more training was to be conducted alongside while in port. Finally, the leadership and values reform focused on “expression of how the values of individuals contribute to effective group mission accomplishment” (Barrett, 2014).

As naval platforms incorporate improved technology and implement unmanned systems, there is the expectation that platforms will function with reduced crewing. As a result, there has been an increased prevalence of sleep deprivation and fatigue among crew members, and the resulting degradation of performance at the individual and unit level. There has been renewed scientific interest surrounding the themes of sleep, fatigue, performance, and endurance, and how the themes interact or influence one another in military environments. While authors’ definitions of each of these themes vary, the recognized side effects among them are similar. Reduced mental capacity, poor decision making, emotional outbursts or withdrawals, and reduced alertness are among the side effects that have been associated with the themes. Perhaps more alarmingly is the association of fatigue and related issues with major maritime accidents.

Recent work by the Australian Defence Science and Technology Organisation (DSTO) has focused on work hours as an indication of rest/sleep patterns for individuals and the individuals’ subsequent performance. A four-month study was conducted as part of the New Generation Navy program, specifically examining People-Focused Work Practices. The study was designed to “objectively measure individual crew work, recovery and sleep hours” (Grech, Roberts, Hamilton, Turner, Cleary, & Warren, 2013) under realistic shipboard working conditions. Grech et al. note that “the final crew

configuration ultimately influences the number of hours worked and hence sleep/recovery time obtained by crew during shipboard operations, subsequently affecting overall crew endurance and safety" (Grech et al., 2013).

In addition, the DSTO has recently conducted two studies of the RAN relevant to crew endurance and the sleep-work hours performed by crews, namely of HMAS *Warramunga*, a frigate, and Australian submarines (2014, in preparation). Currently, the RAN is conducting scenario analysis on workload studies for various platforms. Scenario analysis for HMAS *Choules*, a Bay-class landing ship, was completed using the RAN's proposed NSWW model. Historically, the RAN utilized an information communications technology (ICT) platform called MONICAR to streamline reporting of personnel, competency of skills, training and defect reports. Recently, the platform has been upgraded and integrated into a new system, the Naval Management Diary (NMD). The NMD system is designed to increase the previous functionality offered by MONICAR by increasing efficiencies in ship and crew management, and subsequently fatigue management. The NMD system was trialed during the sustainable workload studies in HMAS *Warramunga*, and further data was collected from Armidale class patrol boats (ACPB) between 2011 and 2013—although this data was not analyzed by DSTO. In addition to NMD data, the studies conducted during these trials also recorded sleep patterns and individual crew members' activities and tasks.

In naval environments where high operational tempo and combat missions exist, crew members often experience additional stressors such as heat, noise, vibration, and confined-space work areas. Substantial effort has been made by individuals and command teams to smoothly adapt to the resulting cognitive fatigue. The United States Naval Postgraduate School has collected several data sets relating to work and sleep hours using similar navy standard work week models. Studies have been conducted on crew members of the USS *Chung Hoon* (DDG-93), a destroyer, and USS *Rentz* (FFG-46), a frigate, and the USS *Port Royal* (CG-73) and USS *Lake Erie* (CG-70), guided missile cruisers, comparing work and daily activities of the NSWW model with the

actual work and activity patterns of the crew members. Collectively, these studies provide specific insight into crew fatigue and performance and informed the methodology used in this study.

The United States Coast Guard also recognized the need to address fatigue, performance, and endurance of its crews, which resulted in the crew endurance management practices guidelines (2003). These guidelines created a pathway for other branches of the military to address the respective roles of command and the individual crew members in combating fatigue within the military. Despite significant efforts in policy and implementation of workforce modeling, such as a standard work week, fatigue is still prevalent and performance degradation remains throughout the maritime environment. Reduced manning, as noted by Grech et al. (2014), has led to a shift in the workload and work-rest schedules experienced by members of the sea-going community. The recent implementation of a standard work week model provides a baseline for measurement of fatigue and performance of small ship crews.

In 2002, the Australia Defence Force released “Fatigue Management During Operations: A Commander’s Guide.” The guide defined fatigue as “the product of intense and prolonged emotional strain, poor and inadequate diet, strenuous physical exertion, unfavorable environmental conditions and sleep loss” (Murphy, 2002). The document urges commanders to “adopt techniques to manage fatigued soldiers other than threat of punishment” (Murphy, 2002). Despite its land operations focus, the guide highlights the potential for personnel and operational costs that are underlined by fatigue, and further, that the requirement for a “thorough knowledge of both sleep and the effects of fatigue are essential aspects of fatigue management” (Murphy, 2002).

The NGN program reached its fifth anniversary in 2014. This milestone provided the Chief of Navy an opportunity to revisit the focus of the program and the work that still lay ahead. Since the program’s implementation, the Chief of Navy has changed to Vice Admiral Griggs. In a statement marking the program’s anniversary, VADM Griggs reaffirmed his commitment to the NGN and its role in cultural reform by stating “NGN is founded on a clear statement of cultural intent. This statement is significant. It is linked to NGN and to the Navy Strategy which is the blueprint for delivering our new capability

and aligns NGN with the broader Defence cultural reform program under Pathway to Change" (Griggs, 2015). VADM Griggs acknowledged the ambiguous and unpredictable environment in which the RAN operates. Further, he conceded that standard rules, processes or SOPs would never be able to cover the gamut of operational contexts. VADM Griggs went on to say that the program has met some success, a notable reduction in training force had been realized and separation rates had been reduced by 25%. VADM Griggs acknowledged this success during his reaffirmation of the program: "Our workforce is in better shape than it was five years ago" (Griggs, 2015).

This thesis offers a closer look into the work week of a typical sailor on an Armidale class patrol boat (ACPB) using a multipronged approach that combines two software tools: the RAN NMD and the Fatigue Avoidance Software Tool (FAST). The major goal of the thesis was to validate the use of the RAN NMD in regulating fatigue management on small ships. A second goal of the thesis was to contribute to the knowledge regarding standard work week models in a sea-going, operational environment. The original intent of the thesis was to use the work, rest and performance data collected on the crew of an ACPB in 2013. However, those data were not of sufficient quantity or quality to allow them to be used for modeling purposes. (The limitations of the 2013 ACPB data are discussed in Chapter II.) Consequently, the thesis simulated typical operations and crew constraints for an ACPB and modeled them for a 3-week underway period using the proposed RAN Navy Standard Work Week model. In addition to meeting operational requirements, the simulated crew had to contribute to vessel maintenance and emergent repairs. This study hinged on simulated crew structures and events based on realistic crew and activity models. During the simulated three-week underway period, the crew undertook a variety of tasks consistent with patrol operations, including boarding party operations. Finally, by utilizing the FAST software, this thesis aims to provide insight into the predicted effectiveness of sailors aboard the Armidale class patrol boats during typical operations, as well as validating the results of the NMD's fatigue management tool.

The following chapter provides a review of the current literature regarding sleep, performance, fatigue, and endurance. The literature review also examines studies of the U.S. Navy Standard Work Week and Australian investigations into fatigue management. The third chapter outlines the methodology used within the study, the fourth chapter offers results of the simulation, and the final chapter offers limitations, conclusions and recommendations of the study.

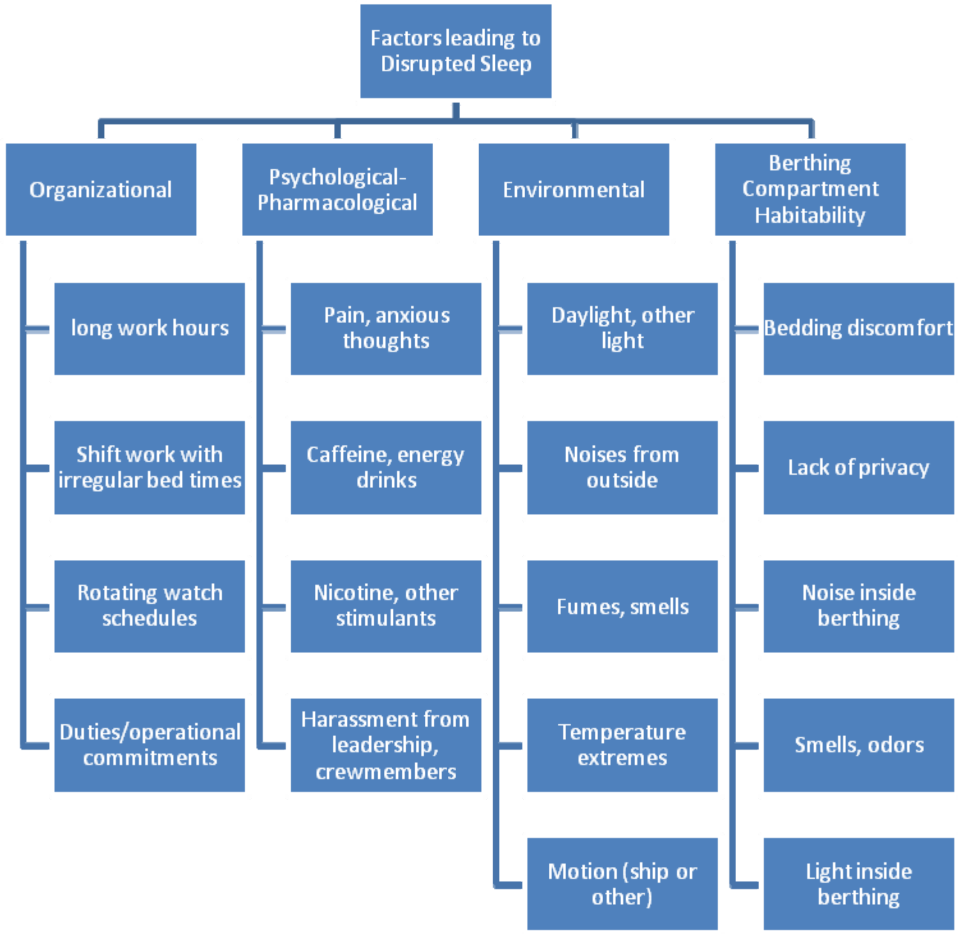
II. LITERATURE REVIEW

> Signs of fatigue soon manifested themselves more and more strongly, and slowly the men dropped out one by one, from sheer exhaustion. No murmur of complaint, however, would be heard.
>
> — Fritz Kreisler, *Four Weeks in the Trenches*, 1915

A. INTRODUCTION

Maritime work environments provide unique “stressor complexes” that contribute to mental and physical fatigue through working conditions, motion, extreme temperatures, poor diet, extreme workload, excessive workday hours, and separations from friends and family (Comperatore, Rivera, & Kingsley, 2005). The maritime and aviation communities, both military and corporate, have become increasingly consumed by the effects of fatigue, notably degradation of performance and the increased potential for accidents. In their study on operational alertness in the aviation community, Rosekind, Neri, and Dinges highlighted that solutions to management of fatigue must be integrated and multi-faceted, stating that “these factors preclude a simple solution and managing fatigue will benefit from addressing education, hours of service, strategies, technology, design, and research” (Rosekind et al., 1997, p. 71). Shattuck (2015) explains that there are many factors leading to disrupted sleep. These factors can be arranged in four broad categories, organizational, psychological-Pharmacological, environmental, and berthing compartment habitability, as shown in Figure 1.

Figure 1. Factors leading to Disrupted Sleep



Adapted from Shattuck (2015)

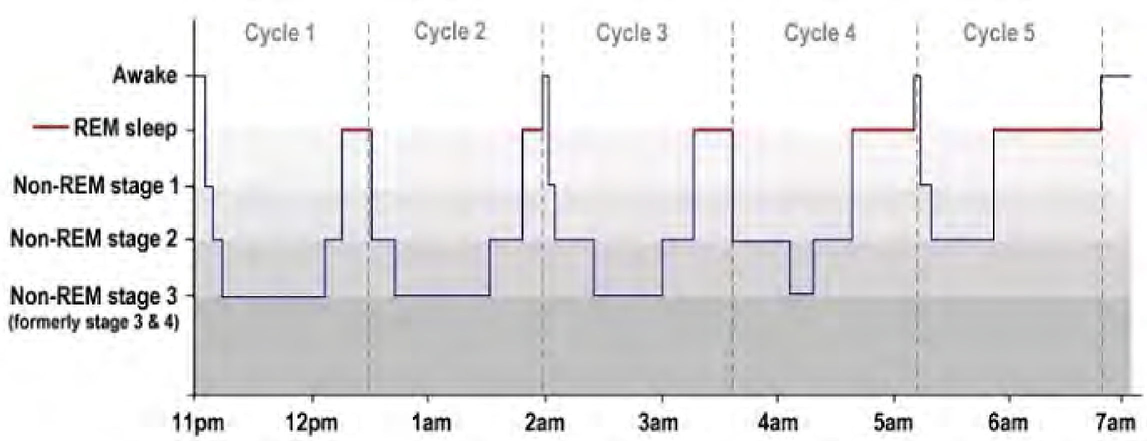
A plethora of scientific literature exists relating to the importance of sleep. The literature encompasses the condition of fatigue and its effect on capabilities such as performance and endurance. The literature review for this study considered sleep, fatigue, performance, and endurance, and their known relationships along with associated measurement tools such as actigraphy, validation, the SAFTE model and FAST software. The review concludes with insights into the emerging tools—Royal Australian Navy's (RAN) Navy Management Diary (NMD), the Navy Standard Work Week (NSWW)—and reviews four previous studies from the United States Navy and the RAN.

B. SLEEP

Sleep is an essential requirement of life for all humans. Without adequate amounts of sleep human performance is degraded. Sleep is defined as “to take rest by a suspension of the voluntary exercise of the powers of the body and mind, and an apathy of the organs of sense” (Webster, 2015). The word itself dates back before the 12th century and has been found in variation in Middle English, slepe; Old English, slǣp; and from the Latin labi, to slip.

In general, sleep is broken into two parts—REM and non-REM. Miller and Firehammer (2007) discuss the differences between the two types and how each has its own set of observable behaviors. Rapid Eye Movement (REM) sleep is a single category of sleep. In contrast, non-REM sleep is divided into four stages as the sleep of the individual deepens, as illustrated in Figure 2. Here, different activities occur in the various stages of sleep. These differences make it important for the individual to gain adequate amounts of both types and all stages of sleep for optimal performance. To achieve optimal performance, the “average adult requires approximately eight hours of sleep” (Miller & Firehammer, 2007; Heisinger, 2009; National Sleep Foundation, 2015).

Figure 2. Sleep cycles throughout sleep



Source: Mastin, L. (2013)

An individual's circadian rhythms act as the time keeper, scheduling bodily functions and periods of sleepiness and wakefulness. Circadian rhythms control numerous factors in the human body including body temperature, sleep-wake cycles, and endocrine functions. The rhythms are "physical, mental, and behavioral changes that follow a roughly 24-hour cycle" (National Institute of General Medical Sciences, 2015). Despite being produced by the body naturally, rhythms respond to levels of lightness, and darkness, and are heavily influenced by the individual's environment. The role of the circadian rhythm is particularly important in watch keeping roles within the military. Watch keeping is a term that describes shift-work in various occupations including the military and first response teams. Haynes (2007) characterizes shift work into three categories: permanent, rapidly rotating, and slowly rotating (p. 8). When considering watch keeping and circadian rhythms, the rate and direction of shift rotation should also be considered (Haynes, 2007).

Figure 3. Circadian Rhythm pattern in 24 hours

Source: Brown (2013)

A common stressor to the circadian physiology of naval crews is the watch schedule that is present in maritime environments. Such a schedule is further complicated by rotating shifts and the subsequent shift changes. A rotating watch schedule "not only impacts daily sleep duration and quality; it also desynchronizes the adjustment of the human biological or circadian clock" (Comperatore et al., 2005, B109).

In addition to the long workdays arising from watch schedules and other crew responsibilities, individuals employed in the naval environment are often required to undertake on-the-job training (OJT), which may affect the time available for sleep. As Maquet (2000) observed, sleep is important if the new skill that is learned during training is to be retained: “sleeping during the night after a single training session is critical to skill acquisition” (p. 1235). He further purported that sleep can significantly affect specific types of learning. For example, an individual will have increased REM sleep following training in tasks such as Morse Code. As a result, future performance of recently learned tasks will be impaired if the individual is sleep deprived immediately following the training (Maquet, 2000).

Stickgold, James, and Hobson (2000) further discuss the requirement for sleep following training. The authors specifically considered visual discrimination learning for their study. In support of Maquet’s argument, Stickgold et al. agreed that a lack of sleep following training can interfere with memory consolidation. Further, they suggest that “the occurrence of sleep, rather than a simple passage of time” is required for adequate consolidation of material (Stickgold et al., p. 1237, 2000). Of note, Stickgold et al. also suggest that the first night’s sleep following instruction is critical for consolidation and “subsequent sleep cannot replace the first night requirement” (p. 1237, 2000).

C. FATIGUE

Fatigue is commonly associated with maritime operations and can be defined in various ways. Davenport (2007) described fatigue as the “decline in mental performance, judgement, and complex decision-making, and is associated with a variety of symptoms” (p. 4). Davenport’s (2007) paper also supported the conclusions of Roberts (2012) and Maquet (2000) with regard to learning stating that “depriving the brain of REM sleep by shortening the nightly sleep period from eight to six hours may significantly affect learning and retention” (p. 4).The term does not solely refer to one being tired. Miller (2009) defined fatigue as an “abstract term that describes an internal state of a human operator” (p. 2). Mental and physical performance and various characteristics of performance are also associated with fatigue. For example, reduced mental capacity,

alertness, diminished decision making, emotional outbursts, or withdrawals are also associated with fatigue. Sirois (2009) included loss of emotional awareness, reduced communication abilities, and information processes to the possible outcomes of experiencing fatigue.

The past two decades have seen an increase in military unit command acknowledging sleep deprivation and fatigue and their impacts on individual and unit effectiveness. As Shay (1998) observed, “Disciplined scientific study of the topic may be relatively new, but thoughtful and observant leaders have generally understood sleep deprivation and its effects on individual and unit performance in combat” (p. 93). However, as recently as 2007, some authors have argued that despite the military’s acceptance of fatigue as an operational factor, its existence has become so ingrained in military communities that it is unconsciously ignored. According to Davenport (2007), “Fatigue is so prevalent and such a part of our culture that we scarcely see or recognize it. It’s the big gray elephant we muscle out of the cockpit when we fly, step around when we enter the bridge and push aside when we peer into the periscope” (p.5). Kilshaw (2008) went further to suggest that when considering the treatment of fatigue as a symptom of Post Traumatic Stress Disorder (PTSD) a culture exists where a “stiff upper lip” must be maintained (p.222). Further still, Kilshaw suggests that the psychiatric discourse that goes along with treatment was at odds with the “hegemonic ideal of masculinity in UK military culture” (2008, p. 223).

Fatigue has been found to affect many facets of performance in the maritime environment. Green (2012) and Davenport (2007) suggest an individual’s training, education, personality, or motivations are not the cause of the fatigue related decrements. The only cure for fatigue is sleep. Sleep allows the individual to recover from the fatigue that the mind and body is under; prolonged periods of fatigue may have increasingly detrimental effects. Policy makers and command teams must address Davenport’s (2007) observations that militaries have accepted and essentially ignored fatigue.

D. PERFORMANCE

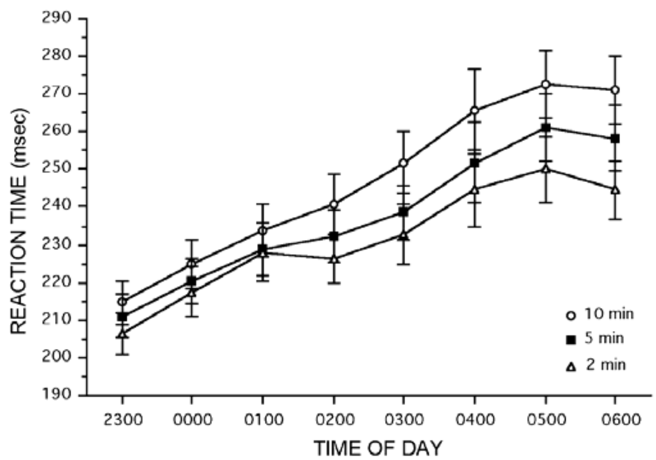
Military environments provide unique conditions in which individuals and command teams are required to perform at high levels for extended periods of time. Miller and Firehammer (2007) argue that the correct number of crew required for ships, submarines, or aircraft squadrons should be determined by what is required to sustain human performance. Grech, Warren, Hamilton et al. (2013) assert that crew size has been minimized by automation and economic reform. Crews can experience significant side effects from prolonged exposure to high operational tempo and combat environments and must adapt to manage cognitive fatigue (Miller & Firehammer, 2007). Babkoff, Kelly and Naitoh (2001) highlighted the degradation of performance when exposed to long-term sleep deprivation resulting in "decrements in cognitive and psychomotor performance" (p. 1). Further, they highlighted the impact of "various stimuli and environmental variables" (Babkoff, Kelly & Naitoh, p. 2, 2001).

Objectively measuring performance is a complex task. One common way of measuring vigilance performance is the Psychomotor Vigilance Test (PVT) (Dinges & Powell, 1985). Generally conducted as part of sleep deprivation studies, the PVT is a standardized test typically ten minutes in length. Participants are required to press a button in response to seeing a stimulus (flash of light or color change). The test has multiple stimuli at random intervals within the testing period. The PVT is easy to administer in clinical conditions and, as noted by Loh, Lamond, Dorrian et al (2004), methodically reliable. However, in a military environment, operational tempo may not allow for ideal testing conditions. Loh, Lamond, Dorrian et al. set out to test if PVT could be administered in shorter periods than the standard ten minutes. Their motivation for the study was to test the validity under less-than-ideal conditions. The authors suggest that shorter testing periods could benefit time-constrained work environments including aircraft flight decks and air traffic control rooms. By extrapolation, a shorter test could also be appropriate in the maritime environment where workers are often hindered by similar constraints as aircraft work environments.

Mean reaction time results from Loh, Lamond, Dorrian et al. are illustrated in Figure 4. The authors found that their results were in line with previous research,

specifically that “psychomotor vigilance performance during the 10-min PVT deteriorated with increasing wakefulness” (Loh et al., p. 342, 2004). Further, the authors found that for each measure; RT, optimum response, response in lapse and percentage lapse; the weakest performance was recorded at 0500 h. This finding corresponded with a natural circadian trough that generally occurs between 0400 and 0600 h.

Figure 4. Mean reaction times during the whole 10 min, the first 5 min, and the first 2 min of PVT. Error bars represent 95% confidence intervals.



Source: Loh et al. (2004)

Overall, the authors found that performance declined during the first 2 and 5 minutes of the 10 min PVT. However, they caution that despite the results supporting the hypothesis that RTs “during the first half of a 10 min PVT are sensitive to the effects of sleep loss,” the RT metric suggests that the “sensitivity to sleep loss decreased with decreasing time on task” (Loh et al., p. 345, 2004). Concluding remarks suggest that while the shorter tests are valid, the 10 min test is preferable unless operationally not feasible. Operational studies default to 3 minute PVT due to constraints imposed on the researchers (Shattuck, Metsangas, Kenney, 2012).

E. COGNITIVE FUNCTIONING AND FATIGUE

In their study, Rabinowitz, Breitbach, and Warner (2009) considered the relationship between fatigue and performance in the aviation community. Their criticisms of previous studies include the lack of inclusion of operational environments and the lack of the use of the tools FAST and SynWin, which measure predicted effectiveness and neurocognitive functioning respectively (Rabinowitz et al., 2009). Their study included predicted effectiveness, predicted fatigue levels, and neurocognitive functioning in a deployed environment.

Rabinowitz et al. (2009) and Shay (1998) conclude that decisions and judgments can have life-and-death consequences and that events occurring as a result of sleep deprivation can include "catastrophic operational failure, fratricide and other accidental deaths, and otherwise preventable noncombatant casualties" (Shay, 1998, p. 97). The need to identify, manage, and adapt to cognitive fatigue becomes critical when considered in light of crew or personnel safety (Miller & Firehammer, 2007; Rabinowitz et al., 2009). Several causes for the decrease in functioning were identified; these include poor sleep quality, restricted sleep opportunities and prolonged sleep deprivation (Rabinowitz et al. 2009).

Rabinowitz et al. (2009) found that fatigue is a pervasive problem in aviation units and should not be assessed by examining quantity of sleep alone. Further, the authors found that the cognitive functioning of the aviators was significantly associated with the individual's alertness and effectiveness prior to the flight. They advocate for the use of tools such as SynWin to identify individuals whose neurocognitive functioning may be affected by sleep restrictions or deprivation but "possess an inherent aptitude for the task demands of flying" (Rabinowitz et al., 2009, p. 361). The highlight of the report was the recommendation to include SynWin data in the initial recruitment of personnel in addition to traditional pencil-and-paper testing which typically only explores IQ factors and personality traits. SynWin may have the potential to help identify individuals who have the aptitude for flying as well as those who may be impaired by sleep loss and sleep deprivation.

F. ENDURANCE

Endurance is described as “a state or quality of lasting or duration” (Webster, 2015). From a military perspective, consideration of endurance is distinct from performance and fatigue, referring to a crew’s ability to sustain a certain level of performance over a given time period. The United States Coast Guard developed specific guidelines to maintain best practices for crew endurance, of which performance is an output. The Crew Endurance Management Practices Guidelines developed by the United States Coast Guard (USCG) outlined the importance of endurance, specifically that the responsibility of maintaining it lies with “vessel captains, department heads, mates, as well as with crewmembers” (USCG, 2003, p. 1). The USCG (2003) described crew endurance as “the ability to maintain performance within safety limits while enduring job-related physiological, psychological, and environmental changes” (p. 3). The definition becomes critical when attempting to provide a holistic approach to crew performance in the maritime and operational environment.

With sailors being the Navy’s greatest strength (Miller & Firehammer, 2007), it is evident that increasing effort has been afforded to facilitate better work practices in order to sustain crew members’ endurance. Militaries provide a unique environment where human capital can rarely be replaced quickly. Operational capability takes priority at all times and crew endurance in order to fulfill that capability is critical. Crew size is determined by manpower requirements specific for the platform and operation, whether it be war or non-warlike operations, humanitarian assistance, or other tasks. If changing crew is not possible, the alternatives for improving existing crew endurance is enhancing productivity or improving performance (Ryan, 2014). Miller and Firehammer (2007) suggest that performance is improved by minimizing fatigue exhibited by crew members. Strategies to minimize fatigue at the command and crew level include enforced periods of rest, optimal watch routine and rest incentives (Ryan, 2014).

G. ACTIGRAPHY

Polysomnography is scientific quantification of sleep that involves data from electroencephalogry (EEG), oxygen levels in the blood, heart rate and breathing patterns, and eye and leg movements (Mayo Clinic, 2015). In most cases polysomnography is used in clinical environments to monitor “sleep stages and cycles to identify if or when your sleep patterns are disrupted and why” (Mayo Clinic, 2015). Replacing the traditional polysomnography (PSG), actigraphy can record for varying periods of time: 24 hours, weeks, or even longer. Wrist worn actigraphy has been used for over thirty years to study sleep and wake patterns in field studies in which polysomnographic studies are too difficult. Actigraphy provides the researcher with useful estimates of duration and quality of sleep in a cost-effective, non-invasive manner. “Insomnia, circadian sleep-wake disturbances, and periodic limb movement disorder” are some of the sleep conditions that can be monitored using actigraphy (Broughton, Fleming, & Fleetham, 1996). The small device is most commonly used on the wrist; however, the trunk of the body and the ankle can also be used if operationally required.

One disadvantage of actigraphy is the potential for incorrect categorization of periods of activity or sleep following periods of inactivity. This issue can result in measurement errors if the individuals’ role requires them to remain stationary for extended periods of time. To overcome this problem, sleep researchers recommend comparing actigraphic data with self-reported diaries of sleep and wake times. The use of sleep diaries is an important adjunct to field studies but care must be taken since self-reported sleep may overestimate the amount of sleep received. Ryan (2014) suggested that a self-reported sleep diary alone also does not account for the quality of the sleep in an objective manner.

H. SLEEP, ACTIVITY, FATIGUE, AND TASK EFFECTIVENESS MODEL (SAFTE)

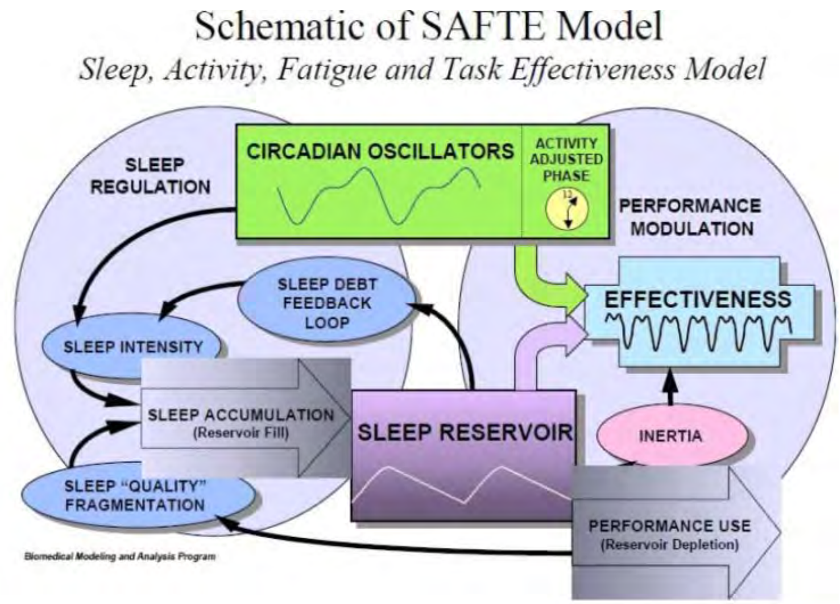
Designed by Hursh and colleagues (2004a), the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model was developed to assist the U.S Department of Defense in identifying sleep-related problems in performance and to assist in developing “operational planning schedule based on hypothetical work-rest-sleep schedules” (Hursh

et al., 2004a). The model is highly suitable for use in the defense environment due to its ability to predict an individual's effectiveness given their past, present and future work-rest schedule (Hursh et al., 2004a).

The SAFTE Model has several advantages over other attempts to model sleep and fatigue (AFRL, 2003). Its key features are easily aligned with the complexities of watch schedules or military capability requirements. Among the advantages, the model accounts for changes in time zone or shift changes, predicts that sleep inertia is proportional to sleep debt, "predicts circadian variations in sleep quality", and "predicts performance limitations under schedules that include daytime sleep" (AFRL, 2003).

The model describes the influence of circadian processes on cognitive effectiveness and sleep regulation. Figure 5 shows the schematic of the SAFTE model. According to Hursh et al. (2004a) the sleep reservoir in the lower center of the figure is "the core of the model." This block represents the individual's capacity to undertake cognitive work. The reservoir is filled as the individual experiences a sleeping period. The level within the reservoir depends on the intensity and quality of the sleep experienced. The reservoir reduces as the individual works or is awake. The intensity of sleep within the schematic can be calculated from the individual's circadian rhythm and the sleep debt, which is the "current level within the reservoir" (Hursh et al. 2004b). The quality of sleep is impacted by the features on the left of the diagram; these factors are mostly external, and may be outside the control of the individual. The right hand side of the model illustrates the predicted measure of effectiveness for the individual based on the input from the left hand side. The model shows that performance effectiveness is the output. The "level of effectiveness is simultaneously modulated by time-of-day (circadian) effects and the level of the sleep reservoir" (Hursh et al. 2004b, p. A45). The final term in the model, inertia, refers to the post-sleep decay of performance.

Figure 5. Schematic of SAFTE simulation model



Source: Hursh et al. (2004a)

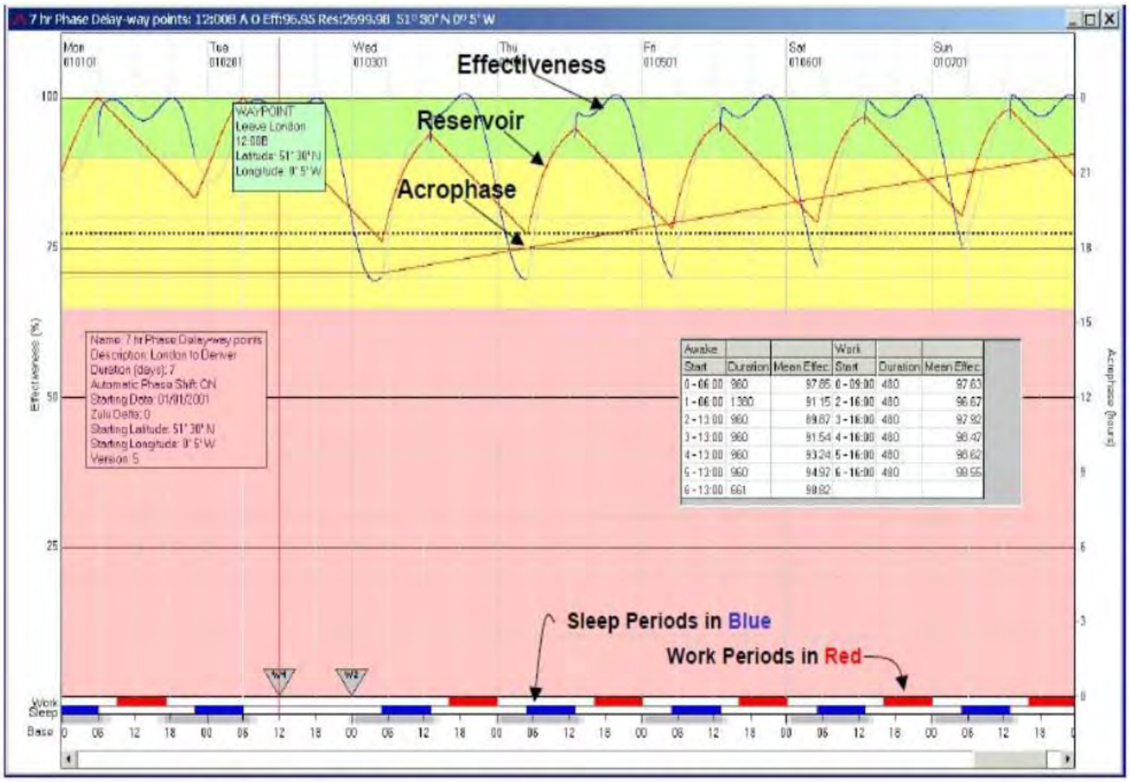
I. FATIGUE AVOIDANCE SCHEDULING TOOL (*FAST*)

The Fatigue Avoidance Scheduling Tool (FAST) is a software program that is based upon the SAFTE model. The program estimates average effects of schedules on human performance, in effect, taking the 72-hour sleep history to predict an individual's alertness level or "predicted effectiveness." Work and sleep data are entered in graphic and text formats and a work schedule is promulgated with a traffic light system (green, amber or red) of classification. The system allows average predicted effectiveness for the measured work periods to be extracted and analyzed. The system creates predictions based on an algorithm derived from over two decades of data collected from the U.S. Army, U.S. Air Force and Canadian researchers (AFRL, 2003). FAST allows for the computation of several metrics for each individual. It can calculate an individual's circadian rhythm, lapse likelihood index, or predicted effectiveness and can compare predicted effectiveness values to a blood alcohol concentration (BAC). The tool has been shown to be highly effective in facilitating the optimization of human performance under constrained conditions, which are inherent in maritime operational environments.

Figure 6 is an illustration of a FAST chart. The top axis of the display is the date, while time in 24-hour periods is given at the bottom axis. Rest and work activities experienced by the individual are indicated by the blue and red bars respectively on the bottom of the chart. The left hand scale ranges from 0 to 100 percent and indicates predicted (ranges from) level of effectiveness for the individual. The traffic light color bands indicate predicted effectiveness or performance levels. Red "indicates an individual's predicted effectiveness is less than 65%; the yellow band indicates predicted levels of greater than 65% but less than 90%; and the green band is predicted effectiveness greater than 90%" (Miller, Matsangas & Shattuck, 2007, p. 241). An optimal level of predicted effectiveness is achieved in the green band.

The BAC calculated by FAST is shown on the right hand vertical axis when selected on the schedule display (Figure 6). The BAC levels illustrated by FAST should be used with caution when evaluating predicting effectiveness of the individual. The BAC scale is included to provide a commonly recognized point of reference for cognitive impairment. The FAST software program points out that the BAC should not be viewed as a precise description of a situation or individual's performance.

Figure 6. FAST Chart



Adapted from: Miller et al. (2007)

The lapse index is another tool in the FAST graphical display. Lapses in FAST are described as excessively long reaction times. These long reaction times could be associated with the commonly used term, ‘micro-sleep’ where an individual falls asleep against their will and often, without warning. In well-rested individuals, the average daily lapse index would range between 0.2 and 1.5. As the individual’s predicted effectiveness decreases, the probability of lapses increase since lapses are the inverse of effectiveness. An individual with an effectiveness of seventy percent would correspond to a lapse index of five; that is, the chance of experiencing lapses is five times more likely than a well-rested person during the average day.

Heisinger (2009) described the FAST software as having the familiarity of a Microsoft Windows application and suggests it is user friendly and intuitive. FAST can provide additional objectivity to performance management for command teams. The tool allows planners to schedule crew work-rest patterns effectively to minimize operational

risks connected with fatigue. FAST can also be used retrospectively to analyze incidents or mishaps where fatigue is suspected as playing a role (Hursh et al., 2004a). Details of the individuals involved can be input and analyzed including sleep habits, schedules, and quality of sleep (Heisinger, 2009). The tool can be analyzed in conjunction with self-reported sleep diaries and ships' diaries to gain a more holistic picture of the events leading up to the incident at hand and the incident itself.

J. NAVAL MANAGEMENT DIARY

The Naval Management Diary (NMD) is an Information Communications Technology (ICT) system developed for the Royal Australian Navy (RAN) that aids in increasing efficiencies in ship and crew management on board. The system attempts to provide a streamlined and automated reporting tool to RAN ships allowing them to focus on "warfighting and maritime operations in Australia and abroad" (K. Ryan, personal communication, September, 2, 2015). The system purports to integrate advanced fatigue tracking, watch keeping, and competency and currency management at the unit and fleet level. Further, the architecture allows input from other standalone systems that manage supporting information such as the human resources tool PMKeyS, and the urgent deficiency (maintenance and parts) tool AMPS (K. Ryan, personal communication, September, 2, 2015).

The NMD provides a real-time, calendar-based, virtual environment that simplifies the units' planning and management. Initial rollout of the system included HMA Ships *Arunta, Parramatta, Gascoyne,* and *Canberra.* This initial rollout sought feedback and suggestions from ship's crew that has been evaluated and developed into the final rollout across the fleet. The prototype of the system provided the system's architecture for the RAN Sustainable Workload Studies in HMAS *Warramunga* conducted by DSTO, and the data collection from the Armidale class patrol boats between August 2011 and December 2013. Individual crew members' activities and sleep patterns were recorded during the study. The resulting NMD can help predict where individuals' opportunity for sleep may encroach upon risk-of-fatigue guidelines (Navy Management Diary Guide, Mar 2015).

The NMD claims to have many benefits over traditional non-integrated systems. These claims include:

- Visibility of personnel and proficiency information for appropriate allocation to events,
- Ability to manage and track performance against RAN Collective Training targets,
- An aggregated view of equipment deficiency information and effect on ship's system,
- Platform capability assessment data is available in a single repository,
- Proactive management of risks associated with individual fatigue,
- Integration with multiple source systems to reduce nugatory data input, improve data quality and streamline reporting,
- Provision of shipboard metrics as an aid to decision-making,
- Collection of seaworthiness and safety related data; and

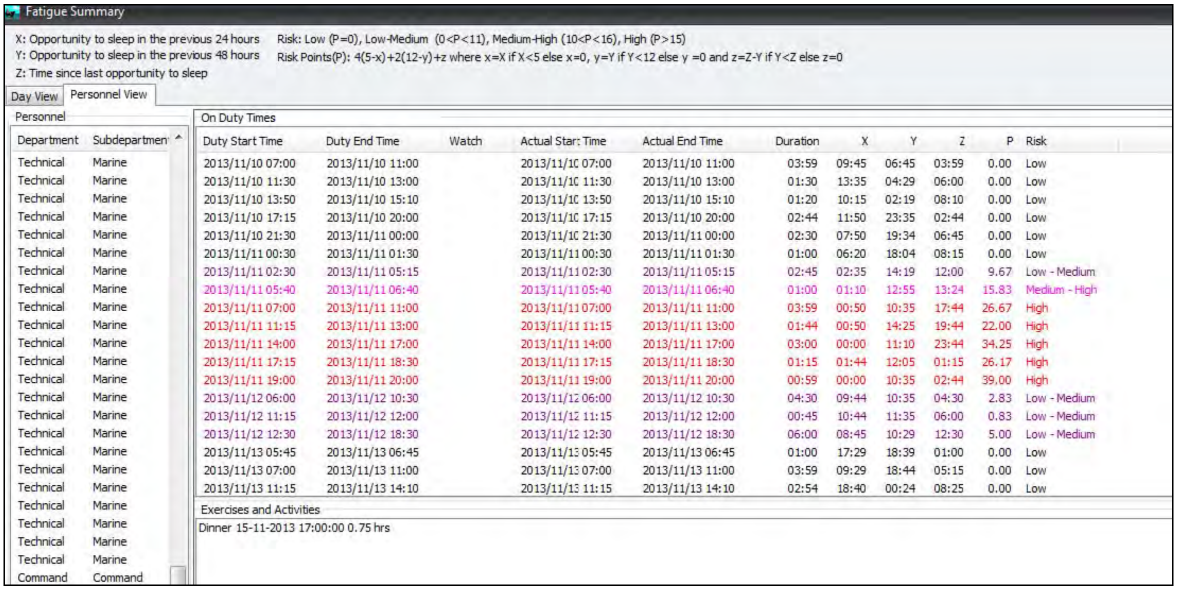
The NMD is capable of exchanging data with several other sources. This feature helps to minimize repetition in data and nugatory reporting. The interfaces operate with varying degrees of maturity. As of March 2015, interfaced systems included the Fleet Activity Schedule (FAMT), PMKeys – responsible for personnel, posting, proficiency, course, leave, and readiness data – AMPS, and Urgent Defect Corrective Maintenance database and the Navy Management Portal (NMP). The NMP interface with the NMD allows for twice daily exchanges of data between onshore and at sea vessel data (Navy Management Diary Guide, Mar 2015).

By using the fatigue monitoring function built into the NMD, various metrics can be extracted. The Fatigue Summary tab allows a visual data set of risk assessments for activity periods to be populated. The left panel allows the user to select individual crew members. Risk assessments are categorized as low ($P=0$), Low-Medium ($0<P<11$), Medium-high ($10<P<16$), and High ($P>15$). The NMD display highlights all events, which are low-medium or higher.

The fatigue summary can provide a snapshot to the command and other users for specific events and allocated personnel, or individual personnel across periods of time.

The NMD fatigue summary page is illustrated in Figure 7. An example of the Personnel Duty Times at Risk is in Figure 8.

Figure 7. Naval Management Diary Fatigue Summary page



Fatigue Summary

X: Opportunity to sleep in the previous 24 hours
Y: Opportunity to sleep in the previous 48 hours
Z: Time since last opportunity to sleep

Risk: Low (P=0), Low-Medium (0<P<11), Medium-High (10<P<16), High (P>15)
Risk Points(P): 4(5-x)+2(12-y)+z where x=X if X<5 else x=0, y=Y if Y<12 else y =0 and z=Z-Y if Y<Z else z=0

Day View | Personnel View

Personnel

Department	Subdepartment
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
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Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Technical	Marine
Command	Command

On Duty Times

Duty Start Time	Duty End Time	Watch	Actual Start Time	Actual End Time	Duration	X	Y	Z	P	Risk
2013/11/10 07:00	2013/11/10 11:00		2013/11/1C 07:00	2013/11/10 11:00	03:59	09:45	06:45	03:59	0.00	Low
2013/11/10 11:30	2013/11/10 13:00		2013/11/1C 11:30	2013/11/10 13:00	01:30	13:35	04:29	06:00	0.00	Low
2013/11/10 13:50	2013/11/10 15:10		2013/11/1C 13:50	2013/11/10 15:10	01:20	10:15	02:19	08:10	0.00	Low
2013/11/10 17:15	2013/11/10 20:00		2013/11/1C 17:15	2013/11/10 20:00	02:44	11:50	23:35	02:44	0.00	Low
2013/11/10 21:30	2013/11/11 00:00		2013/11/1C 21:30	2013/11/11 00:00	02:30	07:50	19:34	06:45	0.00	Low
2013/11/11 00:30	2013/11/11 01:30		2013/11/11 00:30	2013/11/11 01:30	01:00	06:20	18:04	08:15	0.00	Low
2013/11/11 02:30	2013/11/11 05:15		2013/11/11 02:30	2013/11/11 05:15	02:45	02:35	14:19	12:00	9.67	Low - Medium
2013/11/11 05:40	2013/11/11 06:40		2013/11/11 05:40	2013/11/11 06:40	01:00	01:10	12:55	13:24	15.83	Medium - High
2013/11/11 07:00	2013/11/11 11:00		2013/11/11 07:00	2013/11/11 11:00	03:59	00:50	10:35	17:44	26.67	High
2013/11/11 11:15	2013/11/11 13:00		2013/11/11 11:15	2013/11/11 13:00	01:44	00:50	14:25	19:44	22.00	High
2013/11/11 14:00	2013/11/11 17:00		2013/11/11 14:00	2013/11/11 17:00	03:00	00:00	11:10	23:44	34.25	High
2013/11/11 17:15	2013/11/11 18:30		2013/11/11 17:15	2013/11/11 18:30	01:15	01:44	12:05	01:15	26.17	High
2013/11/11 19:00	2013/11/11 20:00		2013/11/11 19:00	2013/11/11 20:00	00:59	00:00	10:35	02:44	39.00	High
2013/11/12 06:00	2013/11/12 10:30		2013/11/12 06:00	2013/11/12 10:30	04:30	09:44	10:35	04:30	2.83	Low - Medium
2013/11/12 11:15	2013/11/12 12:00		2013/11/12 11:15	2013/11/12 12:00	00:45	10:44	11:35	06:00	0.83	Low - Medium
2013/11/12 12:30	2013/11/12 18:30		2013/11/12 12:30	2013/11/12 18:30	06:00	08:45	10:29	12:30	5.00	Low - Medium
2013/11/13 05:45	2013/11/13 06:45		2013/11/13 05:45	2013/11/13 06:45	01:00	17:29	18:39	01:00	0.00	Low
2013/11/13 07:00	2013/11/13 11:00		2013/11/13 07:00	2013/11/13 11:00	03:59	09:29	18:44	05:15	0.00	Low
2013/11/13 11:15	2013/11/13 14:10		2013/11/13 11:15	2013/11/13 14:10	02:54	18:40	00:24	08:25	0.00	Low

Exercises and Activities

Dinner 15-11-2013 17:00:00 0.75 hrs

The fatigue summary function provides several metrics which are combined to calculate a Points score (P) which is translated into the risk ranges. The variables, from Figure 6 and the supporting algorithm are detailed below:

X: Opportunity to sleep in the previous 24 hours

Y: Opportunity to sleep in the previous 48 hours

Z: Time since last opportunity to sleep

P: 4(5-x)+2(12-y)+z = P

Where the following rules apply:

x=X<5 else x=0, y=Y if Y<12 else y=0 and z=Z-Y if Y<Z else z=0.

Figure 8 shows an extract from the fatigue summary produced by the NMD for the CO during the simulation. Periods of activity are listed in the duty start time. These periods vary in length, the duration in noted in the sixth column. This extract illustrated

the different points score (P) associated with calculated risk for the period of time. The duty periods do not account for sleep that has occurred, only the opportunity to sleep external to the duty periods of activity. The NMD does not schedule sleep, meaning that the fatigue summary relies solely on the opportunity to sleep in the previous 24 hours (X) and 48 hours (Y).

Figure 8. Naval Management Diary personnel duty times and associated risk

Duty Start Time	Duty End Time	Watch	Actual Start Time	Actual End Time	Duration	X	Y	Z	P	Risk
2013/11/09 17:15	2013/11/09 18:30		2013/11/09 17:15	2013/11/09 18:30	01:15	11:44	07:44	11:00	0.00	Low
2013/11/10 07:00	2013/11/10 11:00		2013/11/10 07:00	2013/11/10 11:00	03:59	09:45	06:45	03:59	0.00	Low
2013/11/10 11:30	2013/11/10 13:00		2013/11/10 11:30	2013/11/10 13:00	01:30	13:35	04:29	06:00	0.00	Low
2013/11/10 13:50	2013/11/10 15:10		2013/11/10 13:50	2013/11/10 15:10	01:20	10:15	02:19	08:10	0.00	Low
2013/11/10 17:15	2013/11/10 20:00		2013/11/10 17:15	2013/11/10 20:00	02:44	11:50	23:35	02:44	0.00	Low
2013/11/10 21:30	2013/11/11 00:00		2013/11/10 21:30	2013/11/11 00:00	02:30	07:50	19:34	06:45	0.00	Low
2013/11/11 00:30	2013/11/11 01:30		2013/11/11 00:30	2013/11/11 01:30	01:00	06:20	18:04	08:15	0.00	Low
2013/11/11 02:30	2013/11/11 05:15		2013/11/11 02:30	2013/11/11 05:15	02:45	02:35	14:19	12:00	9.67	Low - Medium
2013/11/11 05:40	2013/11/11 06:40		2013/11/11 05:40	2013/11/11 06:40	01:00	01:10	12:55	13:24	15.83	Medium - High
2013/11/11 07:00	2013/11/11 11:00		2013/11/11 07:00	2013/11/11 11:00	03:59	00:50	10:35	17:44	26.67	High
2013/11/11 11:15	2013/11/11 13:00		2013/11/11 11:15	2013/11/11 13:00	01:44	00:50	14:25	19:44	22.00	High
2013/11/11 14:00	2013/11/11 17:00		2013/11/11 14:00	2013/11/11 17:00	03:00	00:00	11:10	23:44	34.25	High
2013/11/11 17:15	2013/11/11 18:30		2013/11/11 17:15	2013/11/11 18:30	01:15	01:44	12:05	01:15	26.17	High
2013/11/11 19:00	2013/11/11 20:00		2013/11/11 19:00	2013/11/11 20:00	00:59	00:00	10:35	02:44	39.00	High
2013/11/12 06:00	2013/11/12 10:30		2013/11/12 06:00	2013/11/12 10:30	04:30	09:44	10:35	04:30	2.83	Low - Medium
2013/11/12 11:15	2013/11/12 12:00		2013/11/12 11:15	2013/11/12 12:00	00:45	10:44	11:35	06:00	0.83	Low - Medium
2013/11/12 12:30	2013/11/12 18:30		2013/11/12 12:30	2013/11/12 18:30	06:00	08:45	10:29	12:30	5.00	Low - Medium
2013/11/13 05:45	2013/11/13 06:45		2013/11/13 05:45	2013/11/13 06:45	01:00	17:29	18:39	01:00	0.00	Low
2013/11/13 07:00	2013/11/13 11:00		2013/11/13 07:00	2013/11/13 11:00	03:59	09:29	18:44	05:15	0.00	Low
2013/11/13 11:15	2013/11/13 14:10		2013/11/13 11:15	2013/11/13 14:10	02:54	18:40	00:24	08:25	0.00	Low
2013/11/13 15:00	2013/11/13 16:00		2013/11/13 15:00	2013/11/13 16:00	01:00	15:00	20:44	10:15	0.00	Low
2013/11/13 17:15	2013/11/13 18:30		2013/11/13 17:15	2013/11/13 18:30	01:14	10:00	18:45	12:45	0.00	Low
2013/11/13 19:00	2013/11/13 21:00		2013/11/13 19:00	2013/11/13 21:00	02:00	07:29	17:44	15:15	0.00	Low
2013/11/14 05:40	2013/11/14 11:00		2013/11/14 05:40	2013/11/14 11:00	05:20	07:24	16:54	05:20	0.00	Low
2013/11/14 11:15	2013/11/14 20:00		2013/11/14 11:15	2013/11/14 20:00	08:44	09:25	15:54	14:20	0.00	Low

The summary tool combines activities scheduled in the NMD Outlook function if there is not a time separation between the events. This means that several events or ship evolutions can be combined and will be read as a single duty period. The Outlook calendar, and subsequently the fatigue summary, do not record nor take into account the sleep of the individual. The fatigue summary is based on previous recorded periods of activity, within 48 hours from the conclusion of the activity being considered. This time period differs from the FAST model, which takes into account the previous 72 hour sleep history.

K. NAVY STANDARD WORK WEEK (NSWW) – RAN SCENARIO ANALYSIS

The U.S. Navy Standard Work Week is described in OPNAV INSTRUCTION 1000.16K (2007) and gives guidance for the usage of total force manpower across all naval ashore units. The OPNAV Instruction is used by the Naval Manpower Analysis Centre (NAVMAC) in conjunction with Type Commanders to determine manpower requirements. The Navy Standard Work Week (NSWW) is a critical element within the Instruction that drives the units manning document (Department of Navy, 2007).

The RAN has adopted a similar approach, designing their own version of a Navy Standard Work Week for the RAN. In 2015, the RAN conducted a workload study aboard HMAS *Choules*. The scenario was based on the completion of activities required by the platform to support a 90-day humanitarian assistance and disaster relief (HADR) operational scenario. Within this scenario-based study, the Navy Standard Work Week, illustrated in Table 1, was utilized.

Table 1. Navy Standard Work Week (RAN)

Hours in a Week			**168.00**
Non-Available Time	Sleep	(8 hours x 7 days)	**-56.00**
	Messing	(2 hours x 7 days)	**-14.00**
	Personal Time/Hygiene	(2 hours x 7 days)	**-14.00**
	Sunday Sea	(3 hours x 1 day)	**-3.00**
Available Time (AT)			**81.00**
Additional Service Allowance	Training – Individual and Collective Training Allowance		**-7.00**
	Service Diversion – Actions required by regulations or standard routine. Includes department musters, rounds, sick parade.		**-4.00**
Productive Time (PT)			**70.00**

Source: HMAS *Choules* WORKLOAD – SCENARIO ANALYSIS (Attachment A to AB22501824)

In the HMAS *Choules* scenario, it was assumed that the productive time available was 70 hours per person per week. The maintenance workload is allocated to enlisted sailors with the rank of Able Seaman (AB). This weekly average is applied to all

departments and work-centers and includes time used for corrective maintenance. The RAN NSWW also assumes that maintenance allocation is only given to Leading Seaman or senior enlisted if the allocated average time is exceeded. The remaining portion is allocated to the higher rank until the allocation is fully used. The NSWW model accounts for watch-keeping, maintenance, service diversion and training. However, the model does not account for day-to-day catering, medical duties, personnel administration or logistics support.

The scenario analysis worked on several assumptions:

1. All positions, RAN and Ship's Army Department (SAD), are filled by appropriately qualified personnel.
2. The minimum number of personnel required for the conduct of each activity/evolution is available from the watch and station bill or supplementary information provided by *Choules.*
3. Watches are 1 in 3, and watch keepers are not utilized for other tasking in the scenario based simulation.
4. Time is allocated as detailed in the proposed RAN Navy Standard Work Week in Table 1.

The resulting workload for each individual per day is then aggregated into the operational phases across a 90-day HADR scenario. The average workload in terms of hours per day, is then calculated to generate a heat map for the positions that are operating at or close to capacity. The resulting aggregates are then averaged for the personnel types (Rank and Category/PQ): "This provides the hours a particular workgroup has to complete, this is then divided by the 70 hours productive time that is detailed in the Navy Standard Work Week and results in the number of personnel of a particular workgroup required to complete the designated activity" (Attachment A to AB22501824). The *Choules* workload scenario found that despite excessive workloads on particular MOSs/Categories, the averaged results indicate that the scheme of complement (crew size and composition) is sufficient to complete 90 days of HADR activities.

L. PREVIOUS US NAVY STUDIES OF SLEEP AT SEA AND NSWW

A thesis by Haynes (2007) considered the work and rest periods experienced by sailors on USS *Chung Hoon* over an 18-day period in 2007. The sample included two officers and 23 enlisted sailors. Participants were from the Combat Systems, Engineering, and Operations departments. Haynes excluded the first two days of the study in order to gain a baseline for the data. This preconditioning period improved the validity of the FAST data which, under normal conditions, assumes a participant received "eight hours of excellent sleep for three days prior to the first studied day" (Haynes, p. 19, 2007). Data were collected through personal Activity Logs and Wrist Activity Monitors. The two sets of data were then validated against each other. Haynes used the NSWW categories as laid out in the Manual of Navy Total Force Manpower Policies and Procedures (OPNAVINST 1600.J). These NSWW categories included watch, maintenance, training, meeting, sleep, messing, personal, and Sunday free time. Haynes found that many sailors reported personal and Sunday free time as the same category, so these groups were combined in the analysis.

A fully compliant sailor that has a work/rest structure according to the Navy Standard Work Week has a predicted effectiveness of 83.25% when calculated in FAST. Haynes (2007) found that only 41% of sailors participating in the study met this level of effectiveness, with 56% of participants having a predicted effectiveness less than 80%. Overall, 85% of participants exceeded the 81 hours of Available Time allocated by the Navy Standard Work Week. Haynes (2007) concludes with two significant recommendations for future studies. The first is to establish department-specific Navy Standard Work Weeks. The second recommendation was replication of the study using more participants and additional platforms in order to derive more accurate standard work weeks.

Green (2009) investigated the Navy Standard Work Week aboard U.S. Navy frigates. Green used data collected from fifty sailors aboard the USS *Rentz*. The sailors varied in rates, ranks, watch stations and departments. Green utilized two methods of data collection, activity logs and wrist activity monitors (WAM). By combining the two methods, the author was able to validate the data more accurately. Participants were

asked to fill in a log divided into fifteen-minute segments using codes under two sections – available time and non-available time. The available section included categories for maintenance, training, meetings, watch stations, and service diversion, and categories of sleep, messing, personal time and Sunday free time for non-available time (Green, 2009, p. 20). Participants were asked to wear their WAM at all times unless an evolution prevented them from safely doing so. Participants were asked to record when they took the WAM off. WAM identification numbers were matched with Activity log identification numbers for ease of correlation.

Final participants varied from initial volunteers in the Green study. Of the initial 50 volunteers, only 24 completed Activity Logs. All participants in the final sample were male with the average age of 31. Green found that on average in a week, participants recorded 20.24 hours more time than allocated for maintenance and exceeded meeting (service diversion) allocation by 7.93 hours. Average personal time was recorded as higher than allocated by 9.29 per week. However, standing watch, sleep and mess exceeded weekly allotment in the NSWW by 16.56, 8.98, and 6.99 hours, respectively. Overall findings by Green for the Navy Standard Work Week and average allocated times are in Table 2.

Table 2. Mann-Whitney U Means Test: Comparison of USS *Rentz* Weekly Averages to NSWW

Comparison of RENTZ Weekly Averages to NSSW

		NSSW	RENTZ	
			(n=21)	
Available Time		81	87.69	(168)
	Maintenance**	14	34.24	(105)
	Trainings***	7	2.08	(21)
	Meetings	4	11.93	(189)
	Watch**	56	39.44	(126)
Non Available Time		87	80.31	(168)
	Sleep***	56	47.02	(42)
	Messing***	14	7.01	(31.5)
	Personal Time*	17	26.29	(147)

Note: Mann–Whitney U in parentheses.
*** p ≤ .000, ** p ≤.01, * p ≤ .05 (two tailed)

Source: Green (2009)

Sixty-one percent of enlisted participants showed that available time was exceeded by the NSWW model (where 81 hours was allocated). (Green, 2009). Green found that the Engineering, Operations and Supply departments all exceed the NSWW allocated duty time (p. 31, 2009). Of the duty time categories, maintenance exceeded the allocated time for all three departments. The watch category was found to be under-allocated in the engineering, supply and operations departments.

Green investigated the sleep patterns recorded by participants against the NSWW Model utilizing FAST. Participants were categorized according to paygrade. Green's results indicate that higher-ranked sailors "self-reported sleeping fewer hours than those of lower rank" (2009, p. 38). Green highlighted several individual cases where the predicted effectiveness was below optimal. Green contrasted below optimal cases with several cases where effectiveness was apparent, however, noting that participants were in

different departments, conducted different watches and the higher effectiveness individual had the opportunity to have 11 hours sleep prior to watch.

Green (2009) discussed the limitations of the study, particularly the small sample size and the “extent to which the conclusions presented here can be extrapolated to larger populations” (2009, p. 48). Further the author noted that human error is possible when participants self-report their work and rest activity data. Finally, the author conceded that the dropout rate for the study was noteworthy. Fifty percent of original participants did not complete the study. Green noted that these individuals may have significantly different results from those found in the final sample.

Haynes used a deviation formula which provided an absolute value; therefore, the difference in actual versus allocated time could not be interpreted as positive or negative, and could have been a combination of both. This differed from the methodology used by Green. Green’s (2009) results were similar to those found earlier by Haynes (2007), specifically that actual hours in the maintenance category were higher than the NSWW allocation. Haynes found that the Combat Systems department had the highest deviation in allocated maintenance hours (11 hours), and concluded that the Navy Standard Work Week “does not adequately capture the required maintenance performed by Combat Systems personnel” (2007, p. 25).

The Green (2009) and Haynes (2007) studies contributed to the military-specific literature regarding sleep and fatigue in the maritime environment. Both studies dealt with small sample groups of participants. Similar to the Australian collection on the ACPB, Green identified participant drop out as a flaw of the study. Haynes did not report this specific negative detail but did suggest that self-reported data posed some concerns.

M. PREVIOUS ROYAL AUSTRALIAN NAVY STUDIES OF SLEEP AT SEA

RAN has conducted two sleep studies on surface ships. The people-focused work practices initiative from the RAN’s New Generation Program led the Chief of Navy to investigate ‘what if’ scenarios as they pertain to fatigue management at sea. The investigation was conducted by the Australian Defence Science and Technology Organization. The resulting report highlights the obfuscation of the environmental,

cultural, and behavioral aspects and the recognition of fatigue as a safety critical problem (Royal Australian Navy 2011 Terms of Reference for NGN Project 13 – people focused work practices monitor load carried by the individual, Navy, N.G., Editor. Canberra).

1. HMAS Warramunga

The HMAS *Warramunga* study was significant in size; work and sleep patterns of one hundred and sixty two members were followed over a four-month period (Grech, Roberts, Hamilton, Turner & Cleary, 2014). Following a review of the scientific literature, the report went on to describe the methodology used in the study. The crew was divided into four groups in order to provide anonymity and improve group sample size. The observational study occurred while the platform was undergoing pre-deployment training (work-up) and assessment, and continued during deployment afloat. Members of the study wore wrist activity monitors (WAMs), and specific device download time was built into the study. Participants were requested to press the event marker on their sleep watch prior to commencing sleep and upon waking. The report notes that this process was not consistent among participants (p. 10) and contributed to error in the data. However, the report goes on to suggest that data fidelity was increased by the use of watches that enabled light levels to be recorded (p. 10).

The DSTO report focused on total sleep time (TST) and total work time (TWT). Further analysis was conducted on the sleep duration, work hours, and indicative fatigue variables between groups, rankings, and departments (p. 12). The DSTO report found all groups to have recorded mean average TST values of less than seven hours during the sea phase of the trial. A single FAST model based on the average daily TST of the entire crew was calculated to approximate average fatigue risk and to highlight the potential impact of work and rest patterns on the ship's crew. The mean TWT increased significantly for all groups at sea (11.2±3.1 h) compared to time alongside (9.4±2.8 h). The report also found that Senior Sailors and Senior Officers had the highest mean TWT while at sea (p. 43). The report suggested that daily sleep was most impacted by operational or mission requirements and operational tempo. Finally, the report conceded several limitations; amongst them:

1. The NMD is capable of interactive changes; however, during the report period, the diary presented schedule working hours as opposed to actual working hours,

2. The modelling tools were limited in scope. Only 25% of the crew were included in the fatigue risk analysis. Secondly, some tools assumed that sleep had been sufficient on previous days, or marked missing sleep periods as zero – subsequently “affecting the cognitive effectiveness / fatigue scores calculated,”

3. The authors concede that the volume of data created challenges in coding – “particularly the absolute accuracy of the coding of individual sleep intervals,” and

4. Raw actigraphic data were not adjusted or corrected for sea state or ship motion.

2. Armidale Class Patrol Boat Data Collection

A second RAN study focused on a much smaller ship and her crew. The Armidale Class Patrol Boat (ACPB) was introduced into service in the Royal Australian Navy in 2005. Typical ACPB operations include patrol in the northern waters off Australia in the Indian Ocean, South Pacific Ocean and Arafura Sea. The introduction of the purpose-built vessels also saw the introduction of the multi-crew system within the ACPB community. At the time of introduction, Chief of Navy Senior Advisory Committee (CNSAC), noted that the multi-crew system would “reduce system risk and provide[s] flexibility to cope with the impact of increased operational tempo and scope to manage operational relief from within the crewing solution” (ACPB Introduction into service information packet). Key points from the crew management environment created by multi-crewing include:

- Annual leave (35 days) available to be used during the course of the year in which it was earned,
- Certainty within the operational program to allow planning towards the use of leave entitlement and other activities,
- Certainty of operational program to allow training to the undertaken. Opportunities to plan for training to assist promotion, personal developments and continuation operational training,
- Provide the majority of training opportunities delivered in the homeport.

Actigraphy (sleep) data, RAN NMD records, and twice daily 3-minute PVTs were collected on volunteer participants in November and December 2013 onboard an ACPB undergoing typical operations. Although personally identifiable indicators were not specifically collected in the data, Personnel Management Key Solution (PMKeyS) (identification numbers) were recorded. PMKeyS data include a demographic profile of the individual as well as other management information including training proficiencies, and deployment history. It was decided that activity diaries would not be kept for the data collection period (Hamilton, S. personal communication, September, 7, 2015). Actigraphy and psychomotor vigilance test (PVT) data were collected using Motionlogger II, borrowed from the U.S. Naval Postgraduate School. The data were recorded and downloaded using Actiware software; formal analysis could not be completed because there were significant issues with participant compliance that were not initially recognized.

Several limitations of the ACPB data collection were identified. The sample population was small. Of the potential 21 crew members, actigraphy data were collected for only 13 participants. This data set was further diluted by poor compliance. Several participants dropped out from the data collection, and others were inconsistent in wearing the wrist monitors. Similar to the data collected by Grech et al., (2014), participants for the ACPB collection were asked to use an event marker to indicate the beginning and end of sleep periods. However, this procedure was not followed by many of the participants, making the actigraphy less easy to interpret and contributing to inaccuracy.

The data were further undermined by the lack of secondary supporting data such as sleep diaries. As previously noted, the NMD was used to record ship and individual events. However, the practice was often predictive rather than reactive; that is, data were not always updated to reflect actual events as opposed to planned events. Further, sleep and rest periods were not recorded in the NMD, making it difficult to match with the actigraphy data. Provision of the watch bill may have also helped validation of actigraphy data but it was not available. The operational tempo experienced by ACPBs was not adequately described by the NMD alone. Performance battery tests (PVT) were also

taken inconsistently and were therefore less useful than desired. All of these issues combined together forced the decision to simulate a crew rather than to use the flawed dataset for this thesis.

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III. METHODOLOGY

The methodology used in this thesis attempts to overcome the shortcomings of both the HMAS *Warramunga* and the ACPB data collection by simulating the work and rest schedules of an entire crew for a three-week underway period in a ‘best case’ scenario. It builds on the lessons learned from U.S. Navy studies and uses the FAST tool to validate the RAN’s NSWW and NMD. Several of the issues identified by Haynes (2007) and Green (2009) were considered during the data simulation for this research. Simulation of data for an entire crew overcame the potential issue of participant dropout. The Microsoft Outlook simulation entered all activities for the individual crew members in an attempt to overcome the errors associated with self-reported data. Sleep periods of six and eight hours were simulated for all crew members to allow for comparison between two sleep allowance levels.

This thesis simulated the 21-member crew structure of a Royal Australian Navy Armidale Class Patrol Boat (ACPB) for a 3-week underway period. This crew included three officers (Commanding Officer, Executive Officer, and Navigator), and a senior enlisted sailor (Chief Petty Officer– Marine Technical (CPO-MT); the remaining were enlisted sailors varying in rank and department. Crew organizational charts are represented in Table 3 and Figure 9. In addition to the three officers, the Command Department included a Petty Officer Coxswain. The Technical Department consisted of the CPO-MT, a Leading Seaman-Electrical Technician, two Able Seaman-Marine Technician, and two Able Seaman-Electrical Technician. The Operations Department consisted of a Petty Officer-Bosun, two Leading Seaman-Bosun Mates, four Able Seaman-Bosun Mates, one Leading Seaman Communication Information Systems, and one Able Seaman-Communication Information Systems technician. The Supply Department included a Leading Seaman Cook, and an Able Seaman Cook. The simulated data from the activities in the 3-week underway period modeled in the current scenario provide the baseline for the proposed RAN Navy Standard Work Week analysis in this study.

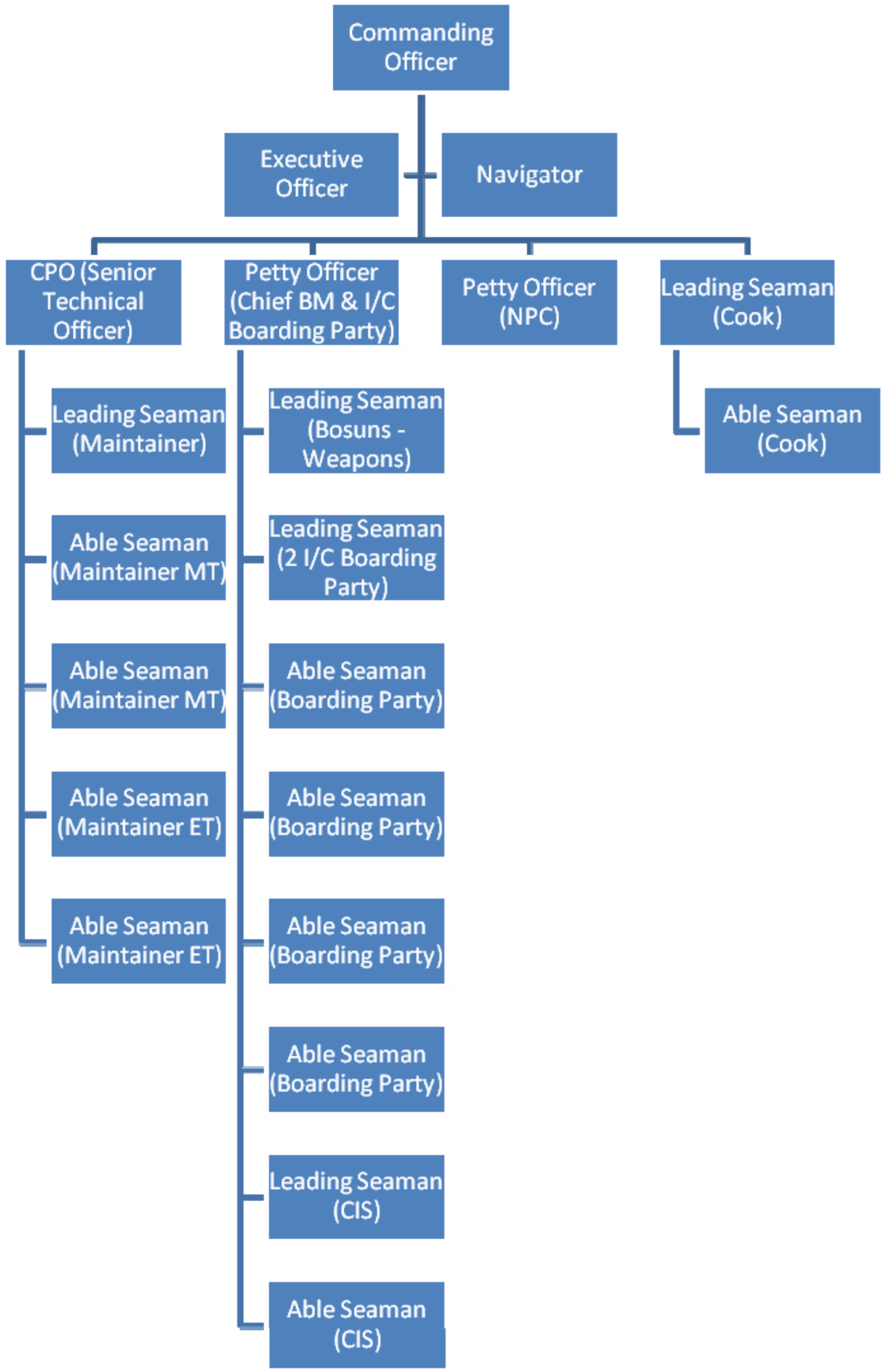
Table 3. Armidale Class Patrol Boat Scheme of Complement

Commanding Officer	C	LCDR SMN
XO/Boarding Officer	C	LEUT SMN
Navigator	B	LEUT
Chief Boatswain Mate & I/C Boarding Team 1	C/B	POB
2 I/C Boarding Team 1	B	LSB
Weapons	B	LSB
2 I/C Boarding team 2	B	LS/PONPC
Boarding Party	C/B	ABBM
Boarding Party	B	ABBM
Gunners Yeoman	B	ABBM
Boarding Party	B	ABBM
Senior Technical Officer	C	CPO/POMT
Maintainer	C	LSMT (E)
Maintainer	C	LS/ABET
Maintainer	B	ABMT
Maintainer	B	ABET (W)
Maintainer	B	ABET
Communications	C	LSCIS
Communications	B	ABCIS
Cook	C	AB/LSCK
Cook	B	ABCK

C=Core ships steaming crew are minimum complement required to sail ship as required by IMO (9 personnel)

B= Members of Boarding Party/Steaming Party or Boats crew

Figure 9. Organizational Chart—Simulated Armidale Class Patrol Boat Crew

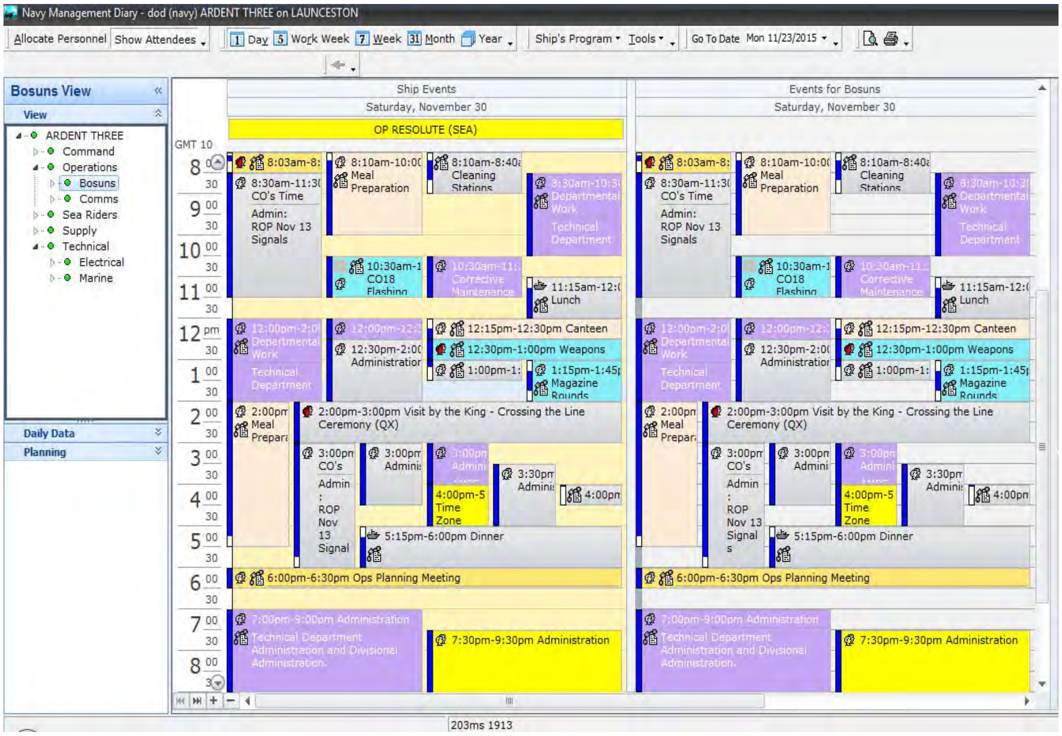


A. SIMULATED NAVAL MANAGEMENT DIARIES AND THE PROPOSED NAVY STANDARD WORK WEEK

An activity diary was simulated in the Royal Australian Navy's Navy Management Diary (NMD) using the Microsoft Outlook function in the NMD, shown in Figure 10. Each simulated crew member was assigned typical duties, meetings, and watches depending on category and specialization (MOS equivalent). NMD schedules were created for 21 crew members across four departments: Command, Technical, Supply, and Operational, similar to actual operations. Not all crew members stood watch. Evolutions, activities, and tasks were created based on rank and department. Some evolutions were deemed 'whole-ship,' in which everyone in the crew participated. Watch standards were applied based on previous NMD data.

An Excel spreadsheet was constructed from the NMD data that divided each crew member's day into 15 minute increments for the entire 3-week underway period. Sleep periods were not included in the Outlook data but were included in the corresponding Excel data. It was assumed that the majority of the sleep occurred between 2100 h and 0600 h. Where watch schedules permitted, sleep was programmed during these times. If watch schedules interfered with programming of eight hours in a 24-hour period, from 0000 h to 2359 h, the additional sleep hours were allocated to the day before. The average sleep was calculated per day to be as close to eight hours as possible without relying on daytime naps.

Figure 10. Example of Outlook Diary for simulated crew member



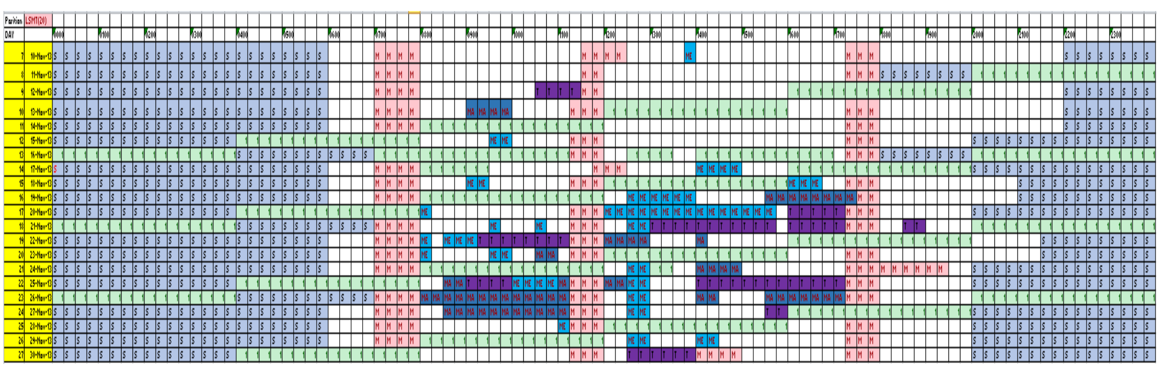
Using the simulated organizational structure and associated ship activities, calculations were generated for each 'participant', yielding total hours of each NSWW category, and also available, non-available, and productive time. The data from the NMD were transcribed into an activity log in Excel. Evolutions and activities were coded according to Table 4.

Table 4. Evolution and Activity Codes

Maintenance (MA)	Watch (1)	Training (T)	Meeting (ME)	Mess (M)
Ready for Sea Chemical Alert Assessments Safety Rounds Dept. work Damage Control Weekly Books Meal Prep	Preboarding activities Vessel Destruction Post-boarding activities Boat transfer Secure to buoy evolution Steaming Party	PILOTEX DCX PT(compulsory) BOARDEX Gunnery Brief MOBEX OOW Manoeuvres Typhoon Firing Ex	Ship Safety Meetings UOF Brief VIP Visit Weapons PM Seamanship Brief	BreakFAST Lunch Dinner Trivia nights

The activity log was divided into fifteen-minute sections to allow for short meetings and evolutions, shown in Figure 11. Evolutions were coded as training, mess, meeting, maintenance, watch, and personal. All codes, except personal, were calculated as fifteen-minute intervals. Personal time was calculated as 24 hours minus all other allocations. For each participant, daily totals, daily averages, 3-week period totals, and 3-week period averages were calculated. The NMD produces a point value for the risk associated with the previous 48-hours of scheduled activity. This point value corresponds with the promulgated risk level for the crew member during a given period of activity. Point values and associated risk are defined as low risk (P=0), low-medium (0<P<11), medium-high (10<P<16), and high risk (P>15). Based on the periods of activity, the metrics provided from the NMD included duration of event, time start and end of the event, hours of opportunity to sleep in the previous 24 hours since the conclusion of the event, opportunity to sleep in the last 48 hours since the conclusion of the event, time since last opportunity to sleep, and the risk points calculated by NMD relating to the events.

Figure 11. Simulated Sleep and Activity Log (NSWW) – Royal Australian Navy Armidale Class Patrol Boat



The U.S. Navy Standard Work Week and the workload allocation utilized in the HMAS *Choules* study were combined to evaluate the simulated data of the ACPB community. Of the 168 hours available per week, 81 hours were allocated to non-available time. This amount includes 56 hours for sleep, 14 hours mess and, 14 hours personal time combined with three hours Sunday sea time. Available time was divided

into seven hours training (collective and individual) and four hours service diversion. Productive time was 14 hours allocated to maintenance and 56 hours to watch (formal watch bill). Some *ad hoc* watch periods were allocated to crew members depending on the specific evolution.

NMD analysis utilized the simulated eight-hour sleep schedules for this component based on the U.S. Navy Standard Work Week and the workload studies conducted on HMAS *Choules* (as shown in Table 1).

B. SIMULATED ACPB CREW—SIX AND EIGHT HOUR SLEEP PROFILES IN FAST

Using the simulated activities from the NMD for each crew member, FAST plots were generated to produce 'predicted effectiveness' for the entire 3-week period divided into 30-minute increments. Since sleep is not set apart explicitly in the NMD, the decision was made to run sets of FAST plots for each crew member. The first set of plots assumed that the crew member had received six hours of sleep in each 24 period; the second set of plots assumed eight hours of sleep per night. FAST schedules were coded as work or sleep. Some schedules had several nap periods during daylight hours due to increased watch schedules. These naps were coded as 'poor' sleep, compared to the sleep during night hours, which were coded in FAST as 'good' sleep.

The summary tables were collected for each 'participant' based on six or eight hours sleep. The 'tabular view' option in FAST provided several metrics for each participant at six and eight hours sleep, namely date, time, lat/long of vessel position, light, effectiveness, and dummy codes for sleep and work (0,1). The tabular view in FAST was programmed to give predicted effectiveness at 30-minute intervals.

C. VALIDATION OF NAVAL MANAGEMENT DIARY USING SIMULATED ACPB CREW

The data were entered into FAST with Darwin, Australia as the location (lat: 12:25:S, long: 130:53:E). The data were entered for the period 10 November 2013 through to 30 November 2013. These dates were used to replicate the time period for the actigraphy data collection for the ACPB community in 2013.

Each period of activity from the NMD was compared to the predicted effectiveness calculated by FAST for the corresponding time period, or as close to the thirty-minute interval as possible. The FAST scores included the overall average for the NMD time interval, the lowest predicted effectiveness level for the interval, and the highest predicted effectiveness. The lowest and highest predicted effectiveness were confirmed by visual inspection of FAST plots. Additional FAST data for each event used included the minimum predicted effectiveness value within the period of activity or duty, and the range of predicted effect during the period of activity. The periods of activity recorded in the NMD and subsequently used in the fatigue summary were generally larger, grouping several daily tasks together, when compared to FAST, which grouped them in smaller periods. The time format of the ‘periods of activity’ in the NMD was compared to the 30-minute interval predicted effectiveness generated by FAST in order to gain data covering 24 hours for the entire three weeks.

Modelling techniques using JMP (JMP12) were then used to analyze the NMD risk profiles against the predicted effectiveness and associated risk calculated by FAST. The five crew members selected from the simulation yielded 443 ‘periods of activity’ from the corresponding NMD activities. Of these periods, four were excluded from the analysis due to erroneous coding within NMD (where P=0, Risk≠Low). A total of 439 periods of activity were used. FAST ‘risk’ for each period of activity was calculated where FASTP = FAST Predicted Effectiveness (8-hours)<77.5%, otherwise no risk. A second set of data was created and entitled FAST 6. FAST 6 was calculated using NMD ‘period of activity’, FAST six hours sleep and minimum predicted effectiveness of less than 77.5 %. FAST ‘risk’=(minimum predicted effectiveness<77.5%). NMD risk levels were coded ordinally, and grouped where

RiskSimplified=Low|P=0

RiskSimplified=High|P≠0

IV. RESULTS AND DISCUSSION

A. SIMULATED NAVAL MANAGEMENT DIARIES AND THE PROPOSED NAVY STANDARD WORK WEEK

The first methodology utilized in this thesis aimed to investigate the validity of the proposed RAN Navy Standard Work Week (NSWW) in a seagoing environment. The results found that overall the NSWW and its categories allocation time did not accurately match the time spent on typical activities by Armidale Patrol Class Boat (ACPB) crew members.

Navy Standard Work Week (NSWW) averages for all crew members were calculated to identify sailors which exceeded the allocated hours for each work category (watch, maintenance, etc.). The simulation results show an underestimation of the productive time used by sailors. The intended formula for productive time assumes 56 hours per crew member of watch time. This amount was not found in the simulation as all crew members experienced an underused watch allocation. Conversely, maintenance was generally in excess of the NSWW allocation. Ranging from -36.08h to +9.25h, the excess in allocated time for maintenance for technical sailors was highlighted. Larger deficiencies were noted for the Able Seaman Cook and Leading Seaman Cook. However, this finding is due to food preparation activity being coded as maintenance. Both these crew members were exempt from machine, engine, or ship maintenance and watch keeping in the simulation. Their allocation of maintenance relates only to the core function of their MOS.

Allocated time for messing was found to be deficient in the simulation although this finding was not considered significant for several reasons. Firstly, standard watch keeping times often interfere with meal serving times, and where this occurred in the simulation, additional eating time was not allocated to the member. Anecdotal evidence would suggest when this occurs in a real environment; meals are kept for the watch personnel and set aside. Trivia night, as a ship’s morale activity, was also coded as mess hours. This evolution ran for ninety minutes and would account for several instances of individual crew member deficiency in the average week. The training category was also

inclined to be overestimated. Activities such as compulsory physical training, and individual and collective training were all coded as training. The simulated schedules did not distinguish between attending and conducting training.

Table 5 illustrates the weekly averages for each NSWW category. The averages showed that no sailor exceed the allocated hours for standing watch (allocation of 56 hours); however, several sailors exceeded the hours allocated for maintenance, training and messing.

Table 5. Summary Table NSWW averages per category

CREW MEMBER	WATCH (NSWW=56HRS)	MAINTENANCE (NSWW=14HRS)	(NSWW=7 HRS)	MEETING (NSWW=7HRS)	(NSWW=56HRS)	MESS (NSWW=4HRS)	PERSONAL (NSWW=17HRS)
CO	15.42	35.67	8.33	8.08	54.75	17.00	28.75
XO	16.42	25.42	9.50	16.92	47.42	15.92	36.42
NAV	49.08	8.17	4.08	7.75	55.92	13.58	29.42
CPO	8.33	50.08	3.67	9.83	56.00	17.67	22.42
ABMT	32.08	29.08	5.33	4.33	53.75	15.08	28.33
LSBM	50.75	5.75	9.25	4.00	55.08	13.00	30.17
LSCK	2.75	40.83	3.58	2.08	56.00	18.50	44.25
ABBM	35.83	9.33	10.25	5.08	53.25	13.00	41.25
ABBM	36.83	6.25	11.00	5.83	54.50	13.58	40.00
ABBM	34.92	5.83	9.08	5.33	54.67	13.42	44.75
ABCIS	3.92	9.58	8.25	5.25	55.83	17.00	68.17
ABET	29.33	15.00	5.58	2.00	55.42	13.33	47.33
LSET	31.33	17.00	5.83	3.92	56.67	13.92	39.33
ABMT	31.33	23.83	3.75	4.00	51.25	11.67	42.17
POB	37.17	6.75	8.17	3.92	53.08	13.92	45.00
PONPC	37.33	4.75	6.50	4.25	51.00	13.08	51.08
ABCK	2.42	40.00	3.83	1.92	56.00	17.67	46.17
ABET	24.58	9.50	1.42	1.67	52.08	9.92	68.83
LSB	36.08	6.75	3.92	3.83	56.08	13.58	47.75
ABBM	34.08	5.08	5.00	5.17	56.00	14.50	48.17
LSCIS	3.25	8.08	2.58	3.75	56.00	18.25	76.08

Formal watch keeping hours were typically allocated to Operations Department sailors, in addition to the Navigator, Executive Officer and Commanding Officer. The Leading Seaman Bosun recorded the highest number of watch hours (50.75hrs). Other senior sailors also recorded high watch keeping hours, 37.17 and 37.33; however, both were under the NSWW allocation of 56 hours. Watch hours amongst the junior sailors within the department were evenly spread with 35.83, 36.83, 34.92, and 34.08 hours (IDs 10, 11, 12, 20, respectively). Of the officers, the Navigator conducted 49.08 hours of

watch on average in the three-week simulation. Ship activities were coded as watch in addition to the tradition watch keeping on the bridge.

Eleven (over 50 %) of the crew members exceeded the allocated NSWW time for conducting meetings, with a RAN NSWW allocation of four hours per week. The highest deficiency was see in the Executive Officer who had several meeting periods allocated to weekly books and administration tasks.

The weekly averages showed that maintenance allocation was exceeded by several crew members, particularly within the Technical Department, shown in Table 6. The Chief Petty Officer (CPO) who is the senior technical officer onboard, exceeded the NSWW allocation for maintenance by 36.08 hours.

Table 6. Difference* in simulated activity and NSWW for technical department

CREW MEMBER	WATCH	MAINTENANCE	TRAINING	MEETING	SLEEP	MESS	PERSONAL
CPO	47.67	-36.08	3.33	-5.83	0.00	-3.67	-5.42
ABMT	23.92	-15.08	1.67	-0.33	2.25	-1.08	-11.33
ABET	26.67	-1.00	1.42	2.00	0.58	0.67	-30.33
LSET	24.67	-3.00	1.17	0.08	-0.67	0.08	-22.33
ABMT	24.67	-9.83	3.25	0.00	4.75	2.33	-25.17
ABET	31.42	4.50	5.58	2.33	3.92	4.08	-51.83

*Difference calculated as NSWW-simulated weekly average

B. SIMULATED ACPB CREW—SIX AND EIGHT HOUR SLEEP PROFILES IN FAST

The second methodology utilized NMD activities and FAST periods of work and sleep to calculate predicted effectiveness. Overall, the results found that the Command Department was at risk of severe degradation in average predicted effectiveness across the 3-week period. Officers and senior sailors in the Command Department recorded four of the six lowest average predicted effectiveness levels over the 3-week period. The overall average predicted effectiveness for the crew ranged from 83.65 % to 90.86 %.

FAST plots were created for each sailor for six and eight hours of simulated sleep. These provide a visual indication of the degradation in performance resulting from the

two hours less sleep and highlight a decrease in performance when only six hours of sleep is simulated.

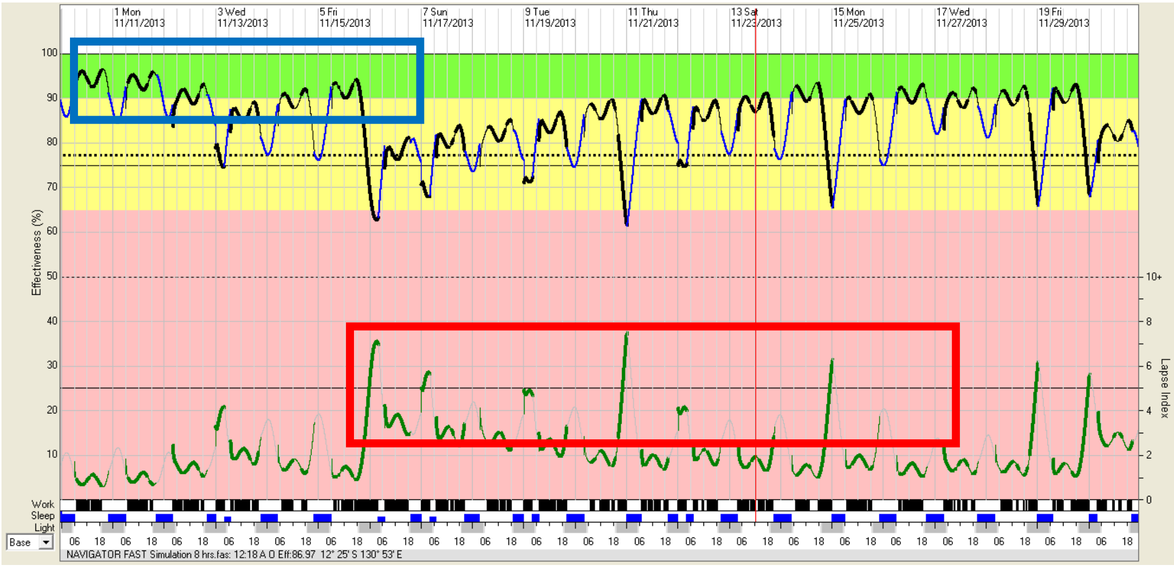
Using the summary tables from FAST, average effectiveness was calculated for each crew member (see Appendix F). These results assume an average of eight hours daily sleep throughout the 3-week period. The tables also illustrate the average predicted effectiveness for sleep, work and wake intervals. These results suggest that the Executive Officer had the lowest average predicted effectiveness for the period. In addition to the lowest average predicted effectiveness, the Executive Officer also had the lowest recorded predicted effectiveness levels for work, sleep, and wake intervals.

Sailors from the Supply and Communication Departments had the highest average predicted effectiveness scores across all the time periods and intervals of the 3-week simulation. The Leading Seaman (CIS) sailor had the highest average predicted effectiveness for periods of activity classified as work for the simulation, assuming eight hours sleep. The Leading Seaman Cook sailor had the highest predicted effectiveness averages for sleep and wake periods. Average predicted effectiveness summaries did not suggest a single department was more or less effective than another.

Cooks (Supply Department) and CIS Junior sailors (Communications Department) had the highest predicted effectiveness overall. Crew members in these departments had regular and 'good' sleep patterns allocated in the simulation. Work activities generally took place during daylight hours and sleep was generally continuous for the six and eight hours nightly sleep allocation.

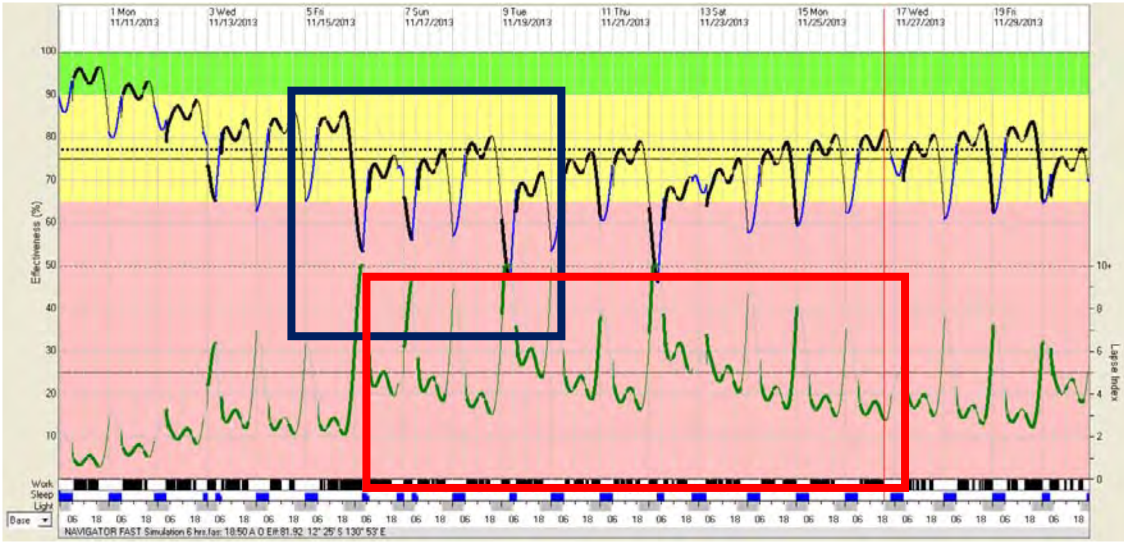
Comparison of FAST results with six and eight simulated hours of sleep provided further insight into the degradation of performance with decreasing sleep. The simulated schedule of the crew's Navigator showed several days across the time period where predicted effectiveness exceeded ninety percent, at Figure 12 blue boxes. The eight-hour sleep simulation resulted in instances of increased Lapse Likelihood Index from acceptable levels, peaking on several occasions with a Lapse Likelihood Index of between seven and eight, see in Figure 12, red box.

Figure 12. Navigator simulated FAST schedule with 8 hours assumed sleep



The same schedule with six hours sleep illustrated a drop in predicted effectiveness that was unable to be regained by the conclusion of the simulation. With only six hours of sleep per night, the Navigator dropped in predicted effectiveness after the second day below ninety percent, and on some days had predicted effectiveness levels below sixty percent, shown in blue boxes in Figure 13. With the same schedule and six hours allocated sleep, the results show peaks of Lapse Likelihood Index in excess of 10, seen in Figure 13, red boxes.

Figure 13. Navigator simulated FAST schedule with 6 hours assumed sleep



The Leading Seaman CIS sailor is an example of a crew member whose role is predominately as a day-hand. Very little tasking occurred prior to 0700 h or after 1900 h. With eight hours of sleep, the crew member gained an average predicted effectiveness of 90.37 %. The predicted effectiveness for the work interval was simulated at 94.02 %, while the sleep interval was estimated at 85.24. The day-hand simulation illustrates how a decrease in sleep would affect the individual. With six hours simulated sleep, the average predicted effectiveness fell to 81.05 %, with work interval effectiveness calculated as 83.89 %. Leading Seaman CIS is illustrated at Figure 14 and 15 for six and eight hours simulated sleep respectively.

Figure 14. FAST Simulation – Leading Seaman CIS
6 hours assumed sleep

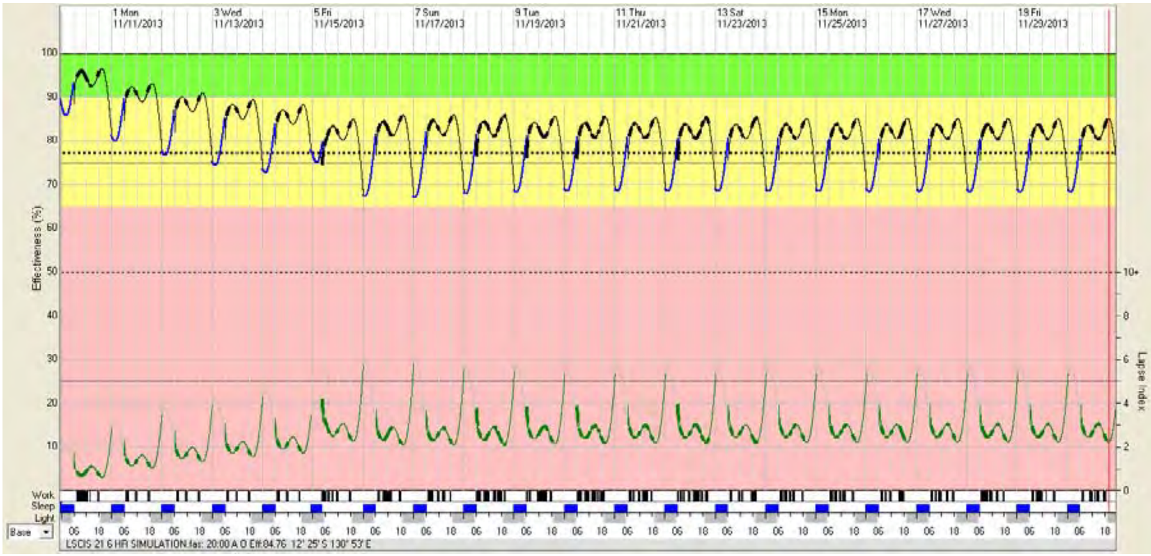
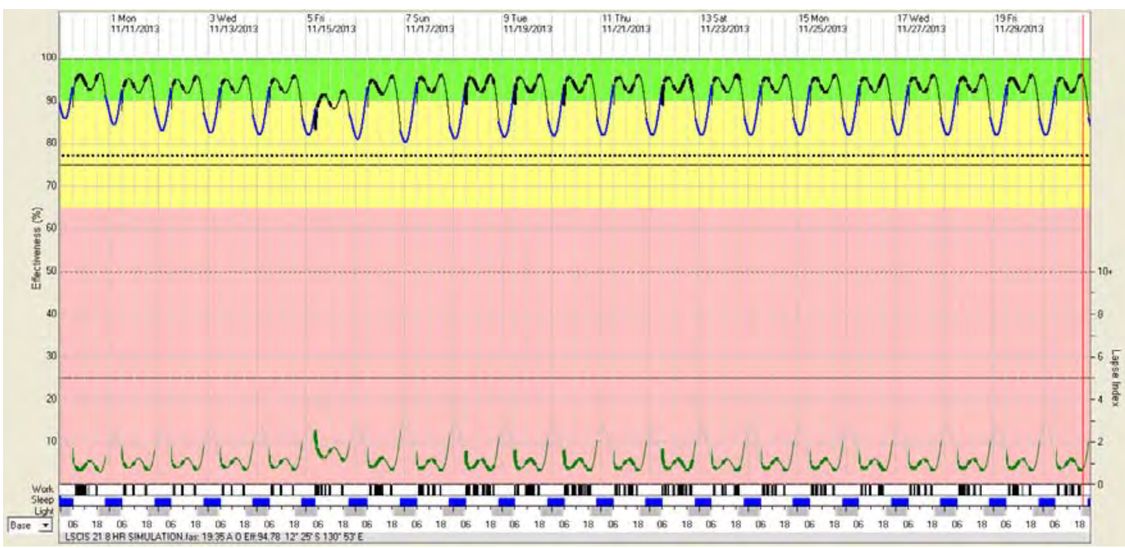


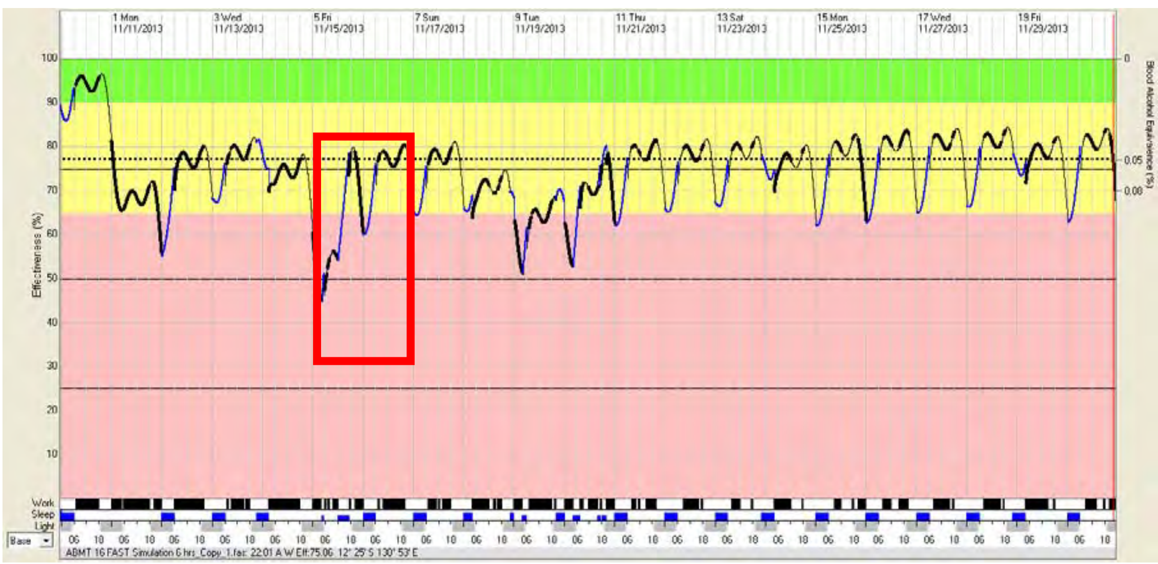
Figure 15. FAST Simulation – Leading Seaman CIS
8 hours assumed sleep



The FAST and NMD simulation provided several test cases for blood alcohol concentration (BAC) indicators. The FAST BAC scale provides a commonly used point of reference for performance and cognitive impairment. The BAC scale is on the right hand side vertical axis of the FAST graph. Select cases from the simulation are shown at Appendix E. Able Seaman Marine Technician (ID 16) is shown in Figure 16 with six

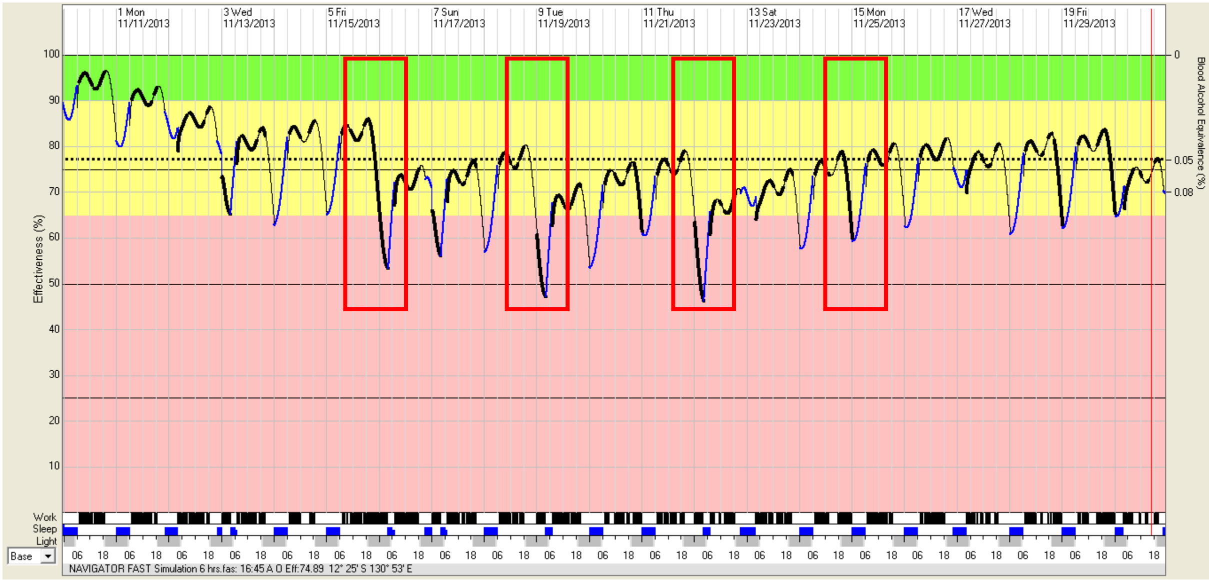
hours simulated sleep on average over the three-week period. During 13 separate watch periods between 1600 h and 0800 h throughout the simulation, the crew member's performance equated to 0.05 BAC or worse. For the six-hour average sleep, the member had an average predicted effectiveness of 74.48%. The work, wake, and sleep intervals for the three-week were 74.89, 75.98, and 68.79 % respectively. The highest BAC for the period was over 0.08% and corresponds with a Lapse Index of 10+ and predicted effectiveness of 45.26 %. This event occurred on the 15th of November, shown in the red box in Figure 16. The member was simulated with a weekly average of 31.33 watch hours and 23.83 maintenance hours. On November 15, the member stood watch for eight hours. Watches were conducted from 0000 h – 0400 h and 2000 h – 2359 h.

Figure 16. FAST Simulation—Able Seaman Marine Technician
6 hours average sleep



Appendix E shows a comparison in BAC for the Commanding Officer with a six and eight-hour sleep simulation. The Navigator's BAC is also shown with six hours sleep. The Navigator's BAC simulation shows several instances where BAC exceeded 0.05 % while on watch, shown in Figure 17.

Figure 17. FAST Simulation—Navigator 6 hrs sleep with BAC



C. VALIDATION OF NAVAL MANAGEMENT DIARY USING SIMULATED ACPB CREW

The final methodology utilized in this thesis was a comparison of the risk levels associated to ‘periods of activity’ that were calculated within the NMD compared to the same periods of activity and their associated risk calculated by using predicted effectiveness in FAST.

Results in Table 7 show statistically significant differences in risk classification between FAST and NMD (Fisher’s exact test, $p<0.001$). Specifically, approximately 83% of the events are classified as low risk both in the NMD ($P=0$) and in FAST, i.e., average predicted effectiveness is greater than 77.5% in FAST. Likewise, 2.73% of events described as high risk in the NMD match the high-risk classification in FAST predictions. However, there is a 14% misclassification rate corresponding to 61 periods of activity in the NMD. Specifically, 11 events that were predicted as high risk in FAST are classified as low risk in NMD. Similarly, 50 events classified as low risks in FAST are classified as high risk in NMD. Cells in Table 7 include the number of events and the corresponding percentage of total number of events.

Table 7. Risk Events (Average Predicted Effectiveness <77.5% with 6-hr sleep)

FAST Risk Level	NMD Risk Level Low	NMD Risk Level High	Total
No Risk	366 (83.37%)	50 (11.39%)	416 (94.76%)
High Risk	11 (2.51%)	12 (2.73%)	23 (5.24%)
Total	377 (85.88%)	62 (14.12%)	439

Results in Table 8 show statistically significant differences in risk classification between FAST and NMD (Fisher's exact test, p<0.001). Specifically, approximately 59% of the events are classified as low risk in both the NMD (P=0) and in FAST, i.e., average predicted effectiveness is >77.5%. Likewise, approximately 8% of the events described as high risk in the NMD match the high risk classification in FAST. However, the remaining 32% of events are misclassified corresponding to 141 events across the 3-week period. Twenty-six events have a low risk prediction in FAST but a high risk prediction in the NMD. Similarly, 115 events classified as low risk in the NMD were identified as high risk in FAST.

Table 8. Contingency Table FAST 6 (Minimum predicted effectiveness<77.5% with 6-hr sleep)

FAST Risk Level	NMD Risk Level Low	NMD Risk Level High	Total
No Risk	262 (59.68%)	26 (5.92%)	288 (65.60%)
High Risk	115 (26.20%)	36 (8.20%)	151 (34.40%)
Total	377 (85.88%)	62 (14.12%)	439

Figure 18 illustrates the NMD periods of activity with FAST minimum predicted effectiveness (six hours sleep) and the corresponding NMD risk levels. Assuming FAST as the valid classification, the black points highlighted in the red boxes represent the

periods of activity that have been erroneously categorized by the NMD. The proportion of erroneous points in the LOW NMD level suggest that the parameters of the NMD metric may be incorrect and may underestimate the associated risk for those periods of activity. Ideally, all points in the LOW NMD level should be above 77.5% on the FAST scale.

Figure 18. FAST 6-hour Sleep Predicted Effectiveness and Associated Naval Management Diary Risk Categorization by 'Period of Activity'

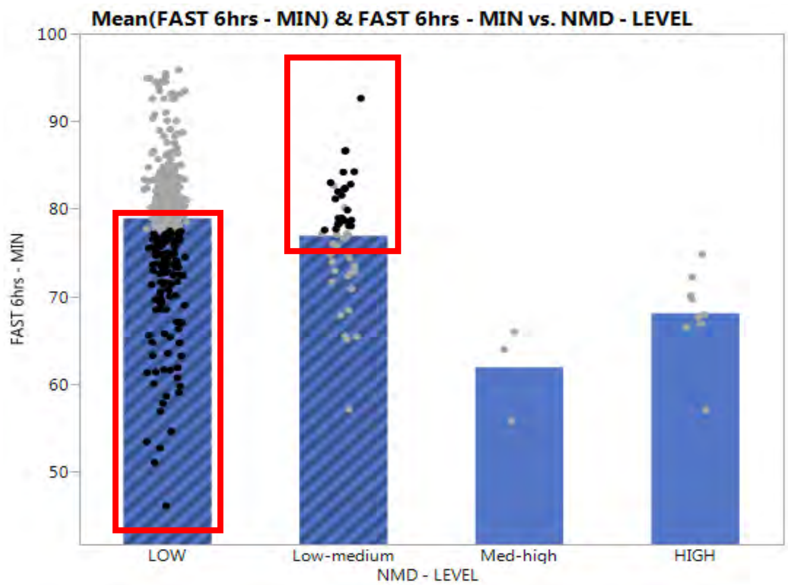


Table 8, which used six hours average sleep, illustrates a more realistic operational picture than that which is provided by other estimates in the study that used eight hours simulated sleep. It is reasonable to estimate 6-hours of sleep per night for individual crew members. The comparison in Table 8 used the minimum predicted effectiveness which illustrates the lowest possible effectiveness for that 'period of activity.'

Several potential explanations could account for the absence of misclassifications in the medium-high and high sections. The sample only included 12 periods of activity associated with these levels of risk. An increased sample size may offer more insight into this relationship. In addition, the parameters of the risk levels may warrant further exploration. The parameters utilized in the underlying algorithm for NMD predicted risk

are limited to the points value which is calculated using opportunity to sleep in the previous 48 hours. The interpretation of ‘opportunity to sleep’ is flawed since the measurement cannot be updated retrospectively, nor can the outcome be improved by actually resting or having sleep. Sleep itself is not used in the calculation within the NMD. The parameters for medium-high were more restricted ($10<P<16$) when compared to low-medium ($0<P<11$); which may account for some events having lower risk assigned to them.

V. CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

This thesis offers insight into the work week of a typical Armidale Class Patrol Boat (ACPB) Sailor. Typical ACPB operations include patrol in the northern waters off Australia in the Indian Ocean, South Pacific Ocean and Arafura Sea. This study hinged on simulated crew structures and events that are based on realistic crew and activity models. During the simulated 3-week underway period, the crew undertook a variety of tasks that were consistent with patrolling operations, including watch standing and boarding party operations. In addition to operating the platform to meet its tasking objectives, the crew had to contribute to vessel maintenance and emergent repairs.

This thesis considered several elements of crew scheduling in the RAN. It examined the proposed implementation of the NSWW, the effects of six and eight hours daily sleep in predicted effectiveness of crew members, and the validation of the fatigue management tool within the NMD for the ACPB community. Based on our simulation of typical seagoing activities for an RAN ACPB crew, results showed that watch standing hours for all crew members were less than the proposed Navy Standard Work Week (NSWW) allotment i.e., the simulated crew was allocated 56 hours of watch weekly but no crew members stood watch for that amount of time. The simulation showed that maintenance allocation was deficient for 10 members of the 21-person crew, i.e., more hours of maintenance were conducted than allotted in the NSWW. In the simulated underway period, technical sailors and officers had more maintenance and were therefore more prone to discrepancies in this category.

Of those personnel who stood watch, none were allocated excessive watch hours in the simulation. Despite this, all crew members standing watch saw a degradation of predicted effectiveness levels in FAST when their simulated sleep decreased from eight to six hours daily. Some of the resulting predicted effectiveness levels – along with their associated Lapse Likelihood Index and blood alcohol concentrations – highlight the concern for watch stander performance when fatigued. The proposed RAN NSWW analysis highlighted the need for further research with a larger data sample and valid tool to ascertain whether there might be a need for platform specific work weeks with NSWW

category allocation specific to occupational specializations. Further, NSWW category allocations should be specific to occupational specialization.

The interpretation of the results for the NMD/FAST validation portion of this study should be applied with caution since only five of a possible 21 crew members were included in this preliminary analysis. However, conflicting results are clearly demonstrated when comparing the risk levels identified by the fatigue management tool in the NMD with the outcomes of models such as SAFTE and FAST. The operational outcomes are also in question. The acceptable level of risk deemed by command varies according to the ship activity and covers a wide variety of factors including environment, operational objectives and individual and collective crew safety.

The methodology of the simulation was flawed in several areas. Activities were coded using the proposed NSWW categories; however, there is some room for interpretation. For example, service diversion, as a category in the NSWW, is an umbrella term that could be applied in different ways. Self-reported diaries could offer further insight into the actual allocation of time of crew members when underway. The results of the current analysis should be viewed with caution and may not be generalizable due to the limitations of the simulation. These limitations include the use of a single platform type and the small size of the crew. The statistical comparisons of risk classifications are based on the assumption of independence. Future efforts with larger data sets should take into account that each participant provides multiple data points. Individual crew members may supply differing numbers of data points as well. Both of these challenges highlight the need for careful attention in using this methodology and also in extrapolation of the results.

The predicted effectiveness simulation using six hours of sleep offered a more operationally valid insight into the predicted effectiveness and potential risk due to fatigue than the eight hour daily sleep simulations since crew members are rarely able to obtain eight hours of sleep each day. A key flaw identified in the NMD model was the assumption of sleep based on the opportunity to sleep or rest. While it would be nice to imagine that crew members always take advantage of opportunities to sleep, this assumption is not warranted. Additionally, several ‘periods of activity’ were found to

have discrepancies from the described NMD risk parameters, i.e., the equations did not generate the expected risk levels. In is current status, the NMD is vulnerable to manipulation of data. The risk status of a crew member can be changed from high risk to low risk simply by deleting events. The danger of this feature is that this change may not accurately reflect their risk level. If the results are altered, the ship's reporting system for risk may be artificially lower than the actual risk level. In addition, these alterations can be made by anyone with access to the NMD. This point highlights the need for the NMD data to be accurate and up-to-date, allowing individuals to precisely record changes that are made to scheduled events. If an individual's events change, the NMD should be updated retrospectively to allow correct assessment of the member's performance.

An additional flaw identified in the study was the classification of events in the NMD. Events were based solely of periods of activity identified by the Outlook function. Time between events was not efficiently calculated or used in the associated risk algorithm. The simulation attempted to overcome this problem but is still based on the 'best case' scenario of six or eight hours sleep per day.

In terms of recommendations, this thesis found a number of potential directions for future research. The NMD and its associated risk levels compared to the FAST predicted effectiveness levels indicate significant disagreement between the two tools. One explanation for this difference is that the results provided by FAST are inaccurate. The disparity may also reside in the points scoring algorithm that underlies the NMD fatigue classification system. Additionally, the weakness may relate to the parameters of the NMD points score for the four levels of fatigue risk currently used. The NMD formulas must be carefully verified in future efforts.

A larger sample size could increase external validity of the results and potentially provide additional insight. Studies using a larger sample size may also benefit from analysis using different NMD risk levels rather than the two that were used in this thesis (i.e., P=0 [LOW], P≠0 [HIGH]). Future studies should also include the time periods not classified by NMD as 'periods of activity', which, in this study were not measured against FAST predicted effectiveness. More accurate studies of real life events using tools such as activity logs and actigraphy while underway would assist in further

validation of the NMD and the proposed NSWW. It is recommended that future studies also compare the NMD risk factors with empirically-derived estimates of performance such as that offered by validated psychomotor vigilance performance testing.

Before the RAN implements major policy changes such as NMD and NSWW, care should be taken to ensure all underlying tools produce valid and reliable results. Neglecting this critical step may result in the misclassification of potential risk and subsequent failure to mitigate threats against safe and effective naval operations.

APPENDIX A. SUMMARY TABLE INDIVIDUAL CREW MEMBER DAILY SIMULATED ACTIVITY (WEEKLY AVERAGES)

CREW MEMBER	WATCH	MAINTENANCE	TRAINING	MEETING	SLEEP	MESS	PERSONAL
CO	15.42	35.67	8.33	8.08	54.75	17.00	28.75
XO	16.42	25.42	9.50	16.92	47.42	15.92	36.42
NAV	49.08	8.17	4.08	7.75	55.92	13.58	29.42
CPO	8.33	50.08	3.67	9.83	56.00	17.67	22.42
ABMT	32.08	29.08	5.33	4.33	53.75	15.08	28.33
LSBM	50.75	5.75	9.25	4.00	55.08	13.00	30.17
LSCK	2.75	40.83	3.58	2.08	56.00	18.50	44.25
ABBM	35.83	9.33	10.25	5.08	53.25	13.00	41.25
ABBM	36.83	6.25	11.00	5.83	54.50	13.58	40.00
ABBM	34.92	5.83	9.08	5.33	54.67	13.42	44.75
ABCIS	3.92	9.58	8.25	5.25	55.83	17.00	68.17
ABET	29.33	15.00	5.58	2.00	55.42	13.33	47.33
LSET	31.33	17.00	5.83	3.92	56.67	13.92	39.33
ABMT	31.33	23.83	3.75	4.00	51.25	11.67	42.17
POB	37.17	6.75	8.17	3.92	53.08	13.92	45.00
PONPC	37.33	4.75	6.50	4.25	51.00	13.08	51.08
ABCK	2.42	40.00	3.83	1.92	56.00	17.67	46.17
ABET	24.58	9.50	1.42	1.67	52.08	9.92	68.83
LSB	36.08	6.75	3.92	3.83	56.08	13.58	47.75
ABBM	34.08	5.08	5.00	5.17	56.00	14.50	48.17
LSCIS	3.25	8.08	2.58	3.75	56.00	18.25	76.08
NSWW Allocation	56	14	7	4	56	14	17

Simulated NSWW Categories in hours assuming 8 hours sleep where possible

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APPENDIX B. SUMMARY TABLE INDIVIDUAL CREW MEMBER ACTIVITY DIFFERENCE FROM NAVY STANDARD WORK WEEK

CREW MEMBER	WATCH	MAINTENANCE	TRAINING	MEETING	SLEEP	MESS	PERSONAL
Commanding Officer	40.58	-21.67	-1.33	-4.08	1.25	-3.00	-11.75
Executive Officer	39.58	-11.42	-2.50	-12.92	8.58	-1.92	-19.42
NAV	6.92	5.83	2.92	-3.75	0.08	0.42	-12.42
CPO	47.67	-36.08	3.33	-5.83	0.00	-3.67	-5.42
ABMT	23.92	-15.08	1.67	-0.33	2.25	-1.08	-11.33
LSBM	5.25	8.25	-2.25	0.00	0.92	1.00	-13.17
LSCK	53.25	-26.83	3.42	1.92	0.00	-4.50	-27.25
ABBM	20.17	4.67	-3.25	-1.08	2.75	1.00	-24.25
ABBM	19.17	7.75	-4.00	-1.83	1.50	0.42	-23.00
ABBM	21.08	8.17	-2.08	-1.33	1.33	0.58	-27.75
ABCIS	52.08	4.42	-1.25	-1.25	0.17	-3.00	-51.17
ABET	26.67	-1.00	1.42	2.00	0.58	0.67	-30.33
LSET	24.67	-3.00	1.17	0.08	-0.67	0.08	-22.33
ABMT	24.67	-9.83	3.25	0.00	4.75	2.33	-25.17
POB	18.83	7.25	-1.17	0.08	2.92	0.08	-28.00
PONPC	18.67	9.25	0.50	-0.25	5.00	0.92	-34.08
ABCK	53.58	-26.00	3.17	2.08	0.00	-3.67	-29.17
ABET	31.42	4.50	5.58	2.33	3.92	4.08	-51.83
LSB	19.92	7.25	3.08	0.17	-0.08	0.42	-30.75
ABBM	21.92	8.92	2.00	-1.17	0.00	-0.50	-31.17
LSCIS	52.75	5.92	4.42	0.25	0.00	-4.25	-59.08

Difference in simulated activity and NSWW hours assuming 8 hours sleep where possible

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APPENDIX C. INDIVIDUAL CREW MEMBER ACTIVITY DIFFERENCE FROM NAVY STANDARD WORK WEEK

Figure 19. Simulated allocation vs NSWW allocation difference results CO (ID 1)

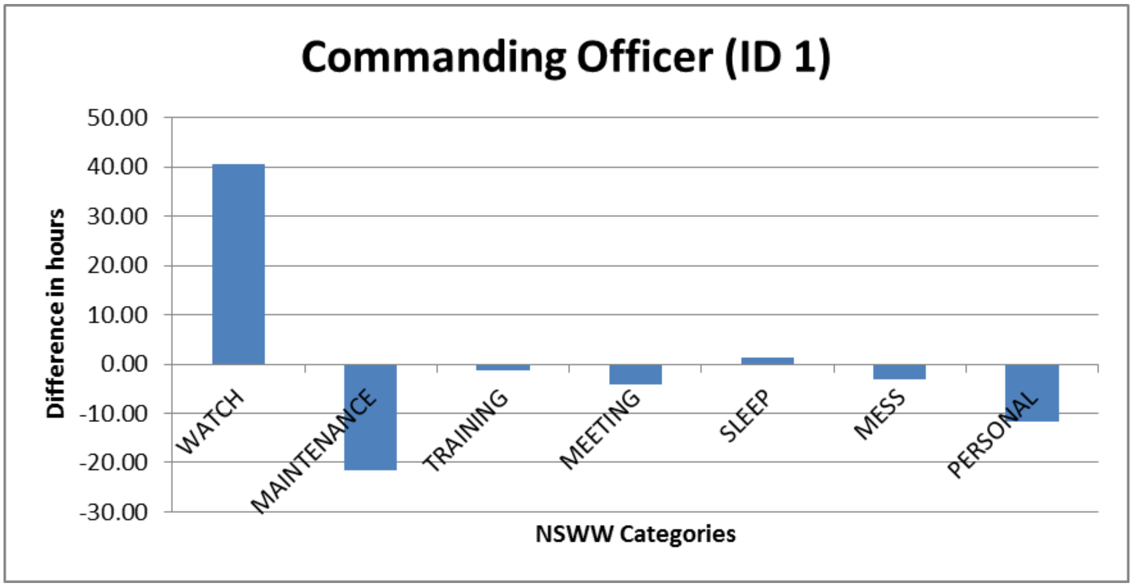


Figure 20. Simulated allocation vs NSWW allocation difference results Executive Officer (ID 2)

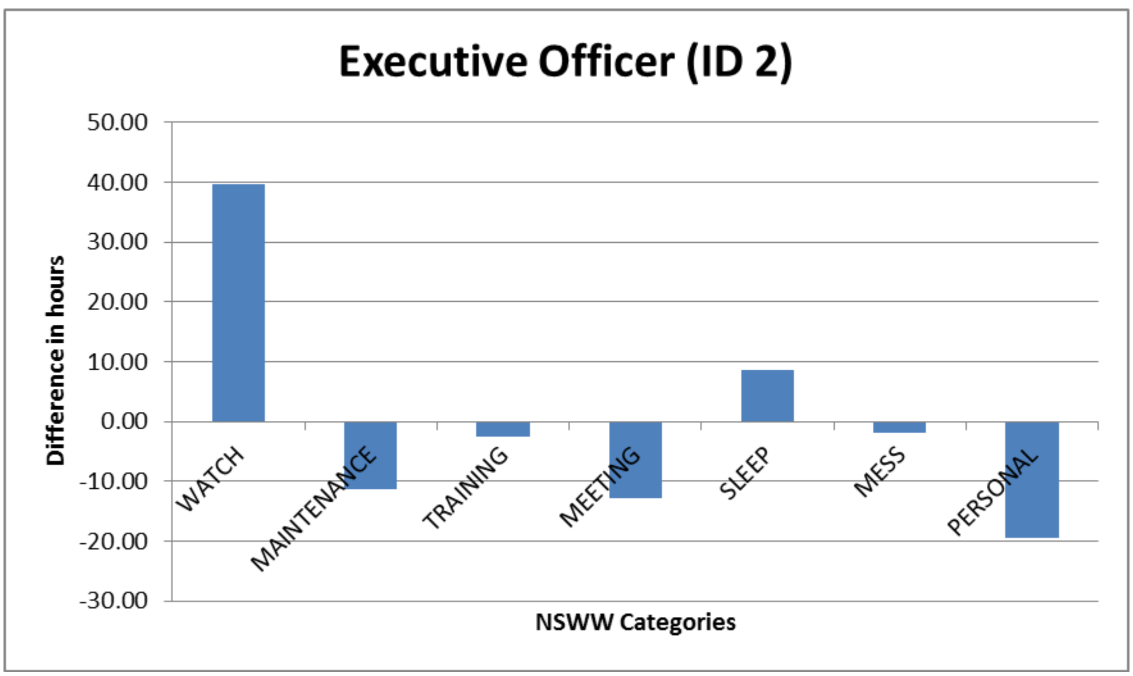


Figure 21. Simulated allocation vs NSWW allocation difference results Navigator (ID 3)

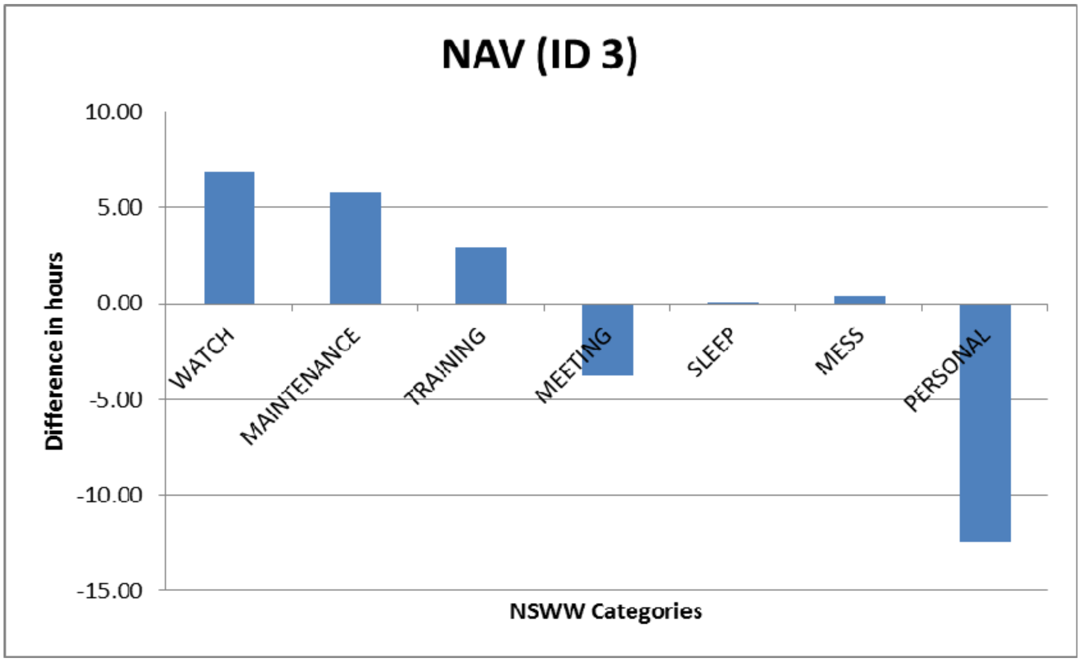


Figure 22. Simulated allocation vs NSWW allocation difference results CPO Senior Technical Officer (ID 4)

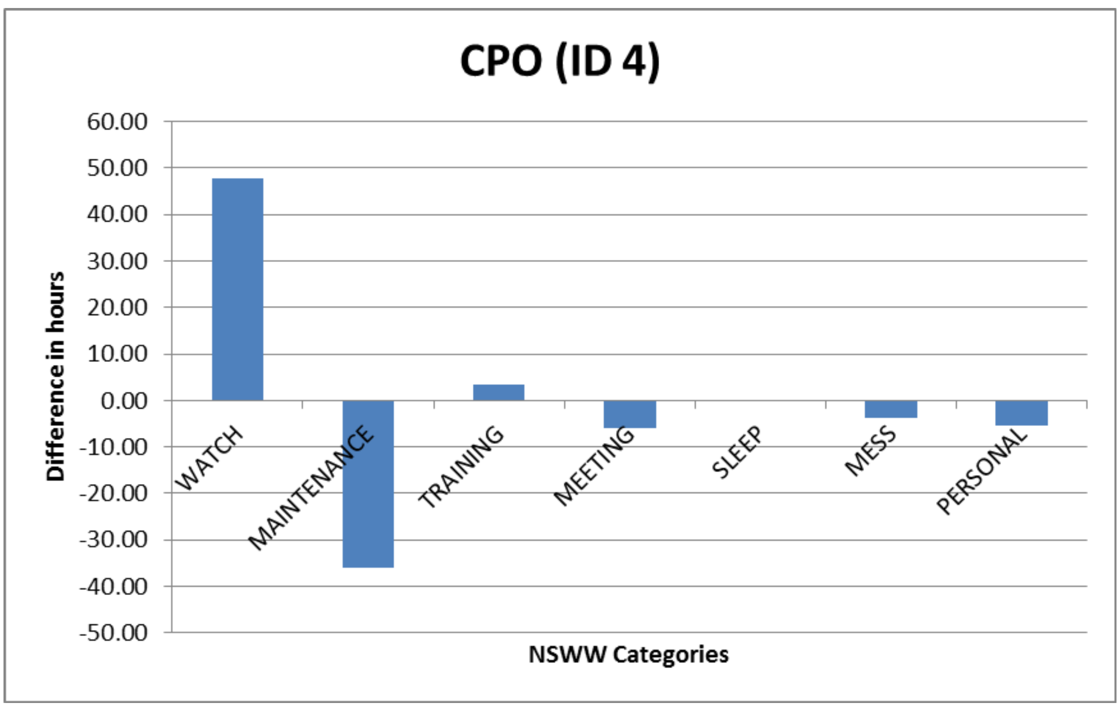


Figure 23. Simulated allocation vs NSWW allocation difference results PO Naval Police Coxswain (ID 5)

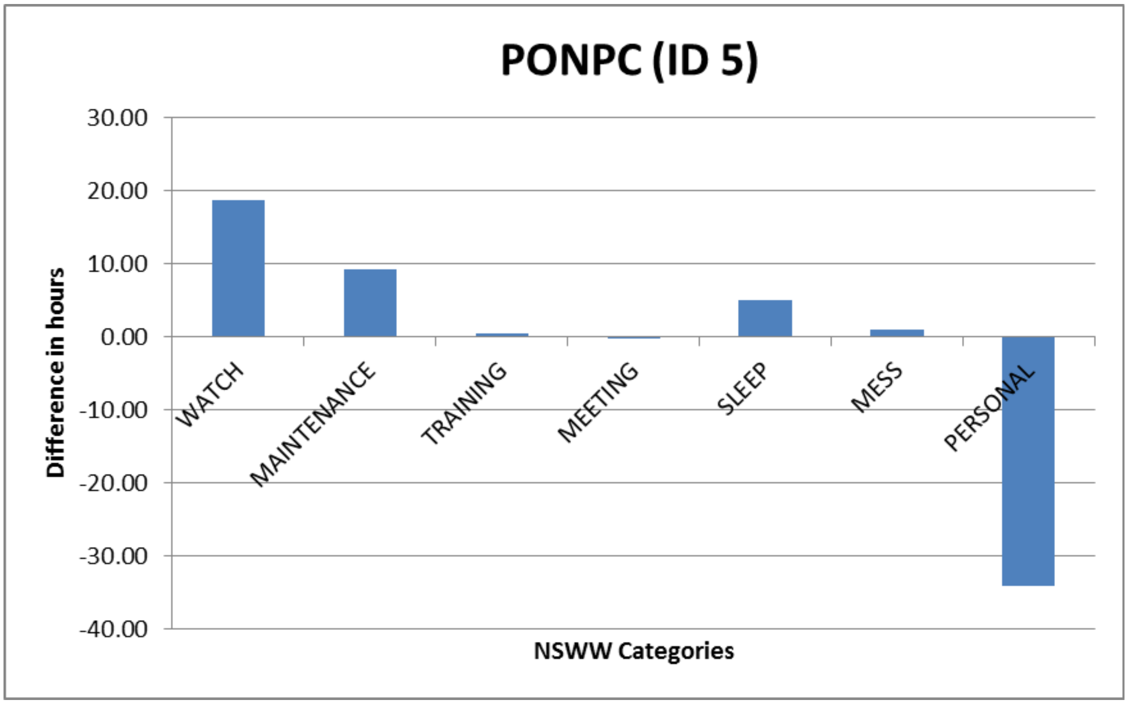


Figure 24. Simulated allocation vs NSWW allocation difference results Petty Officer Bosun (ID 6)

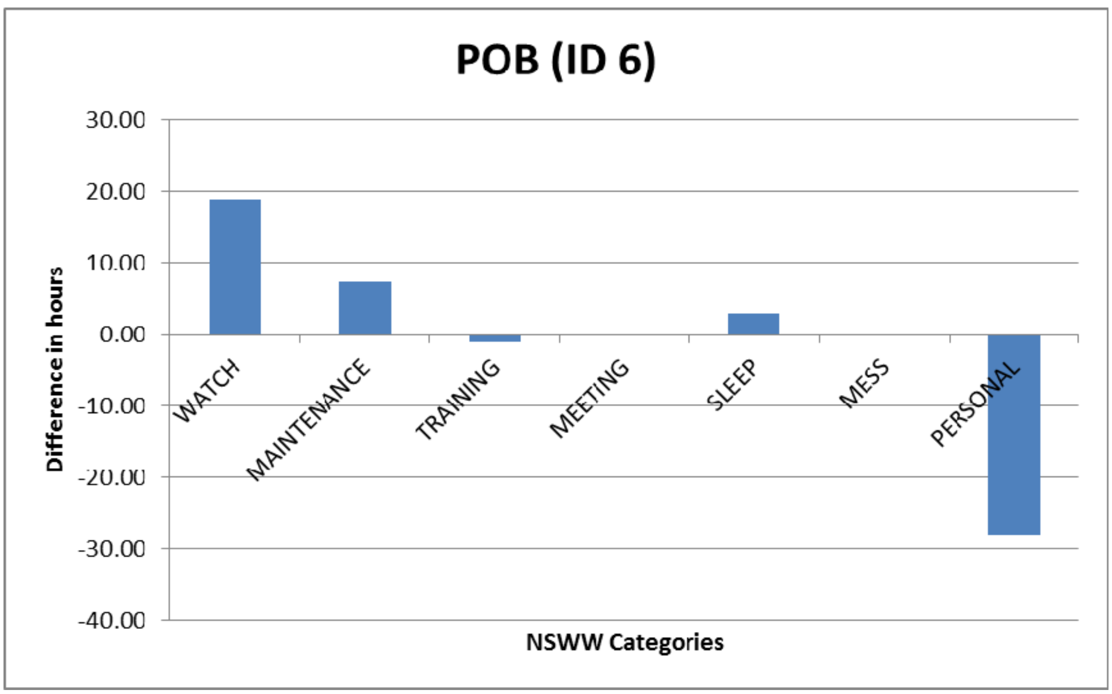


Figure 25. Simulated allocation vs NSWW allocation difference results Leading Seaman Bosun's Mate (ID 7)

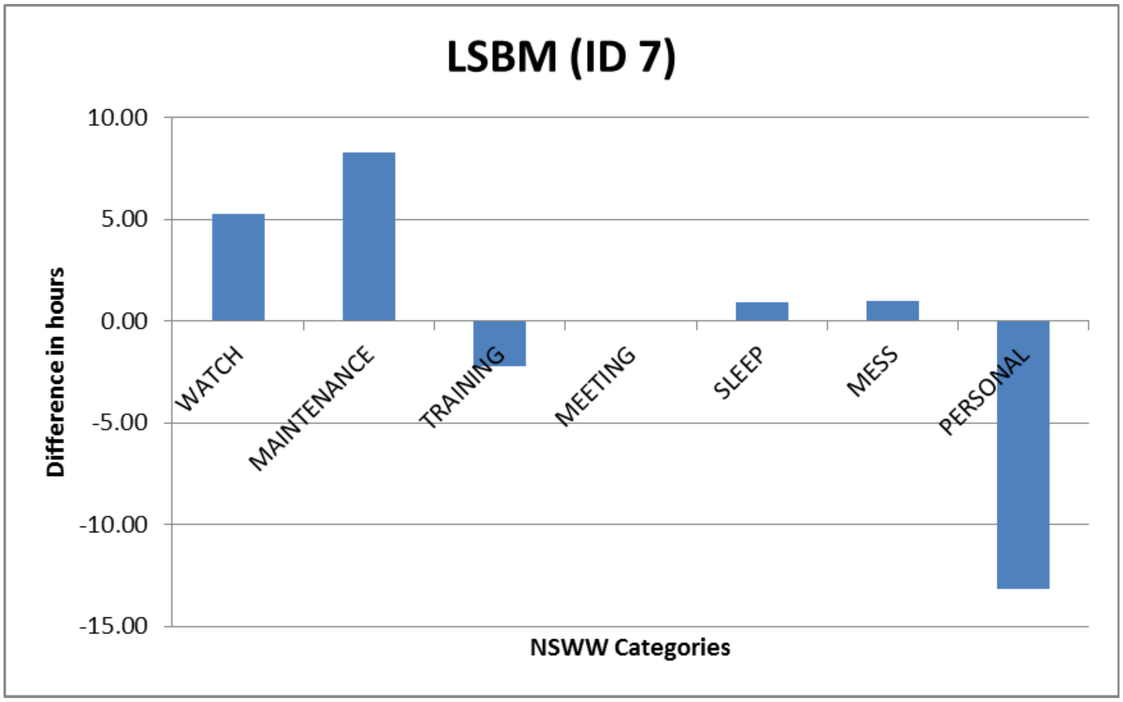


Figure 26. Simulated allocation vs NSWW allocation difference results Leading Seaman Cook (ID 8)

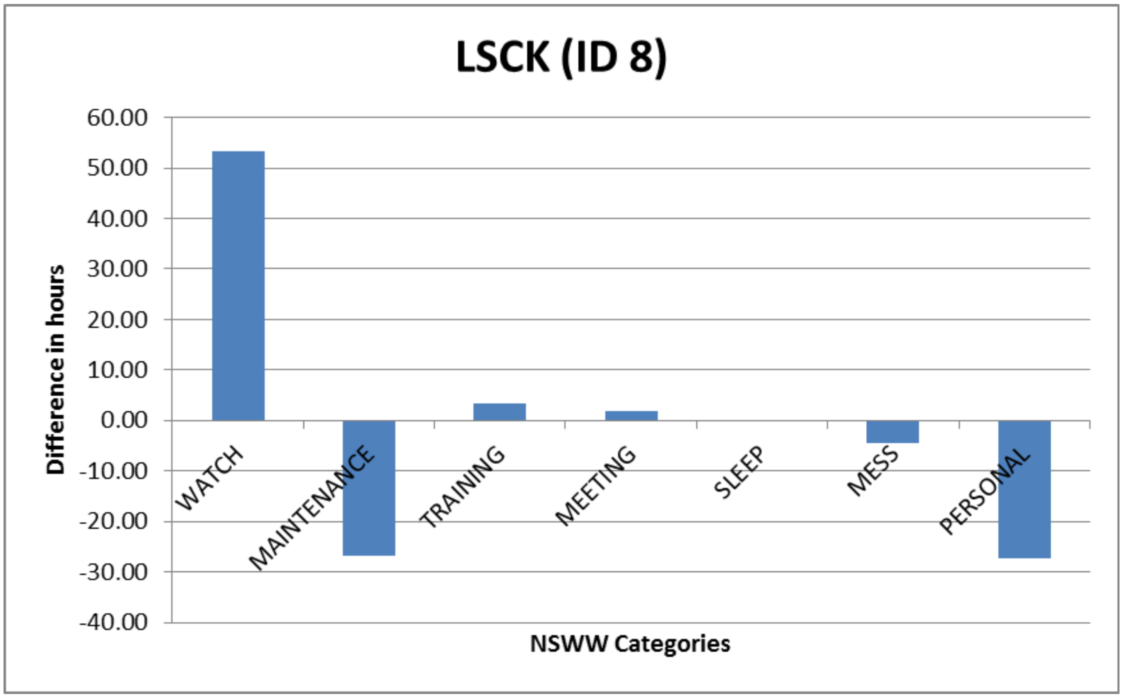


Figure 27. Simulated allocation vs NSWW allocation difference results Leading Seaman Electrical Technician (ID 9)

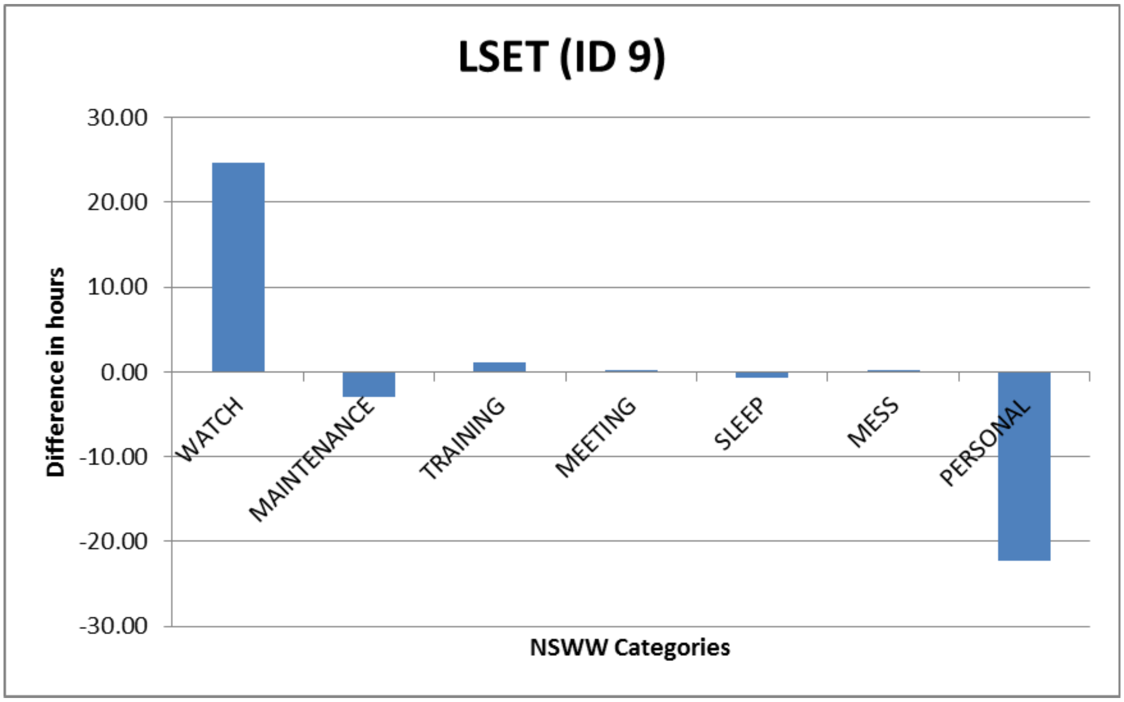


Figure 28. Simulated allocation vs NSWW allocation difference results Able Seaman Bosun's Mate (ID 10)

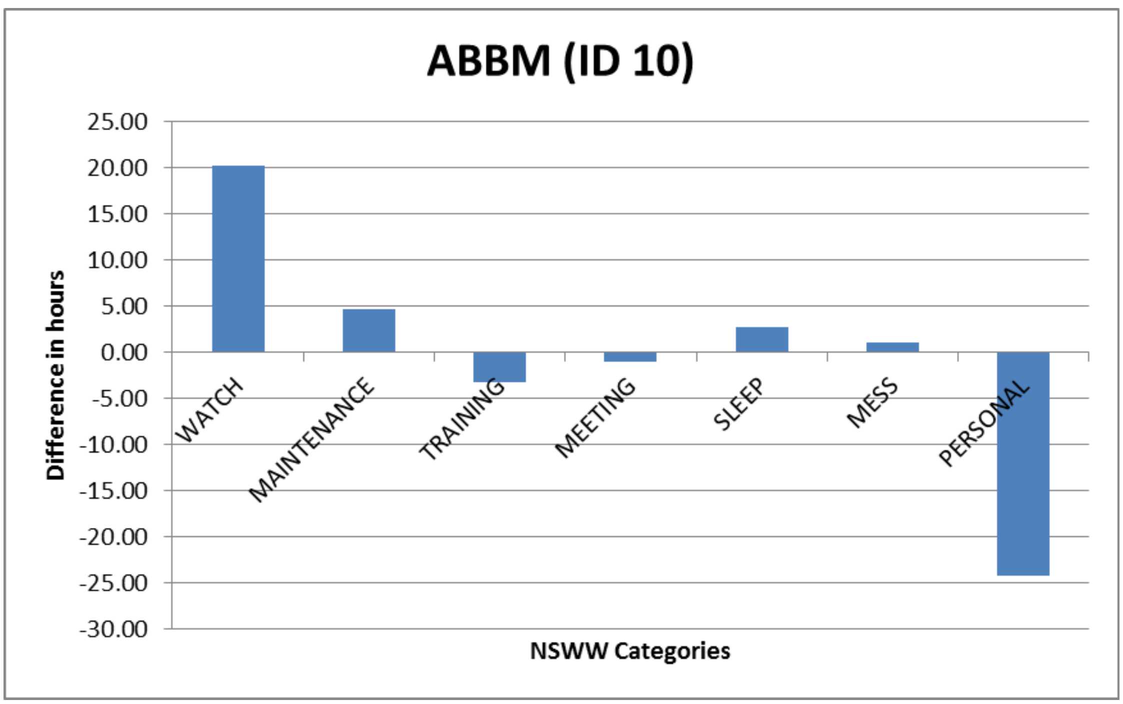


Figure 29. Simulated allocation vs NSWW allocation difference results Able Seaman Bosun’s Mate (ID 11)

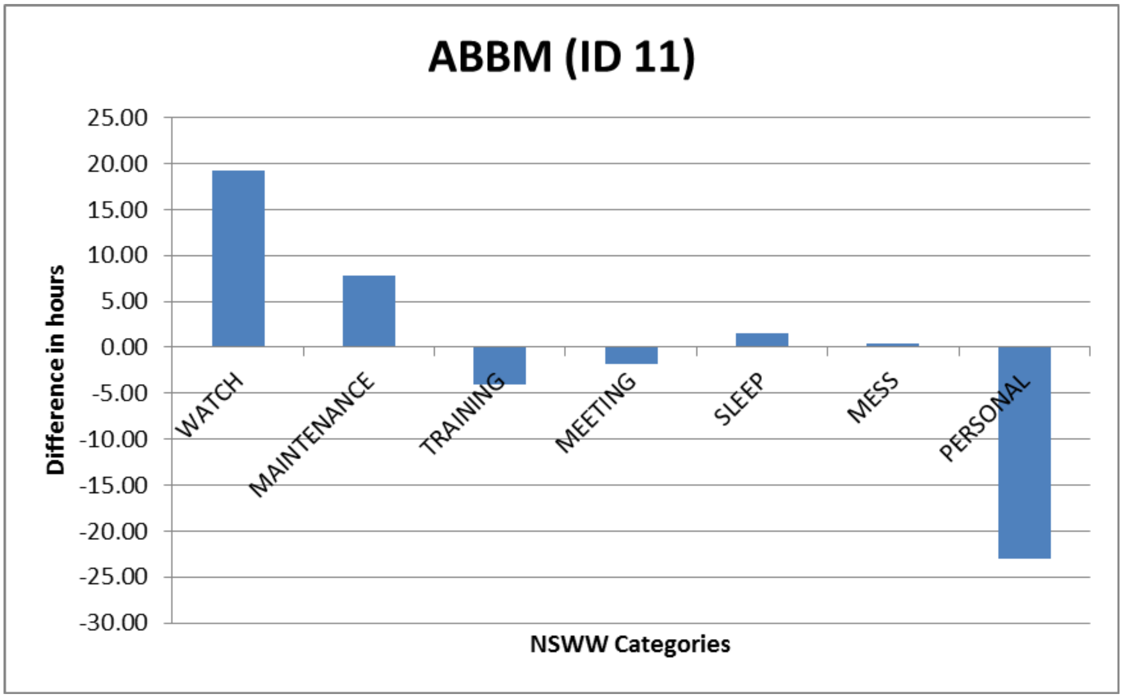


Figure 30. Simulated allocation vs NSWW allocation difference results Able Seaman Bosun’s Mate (ID 12)

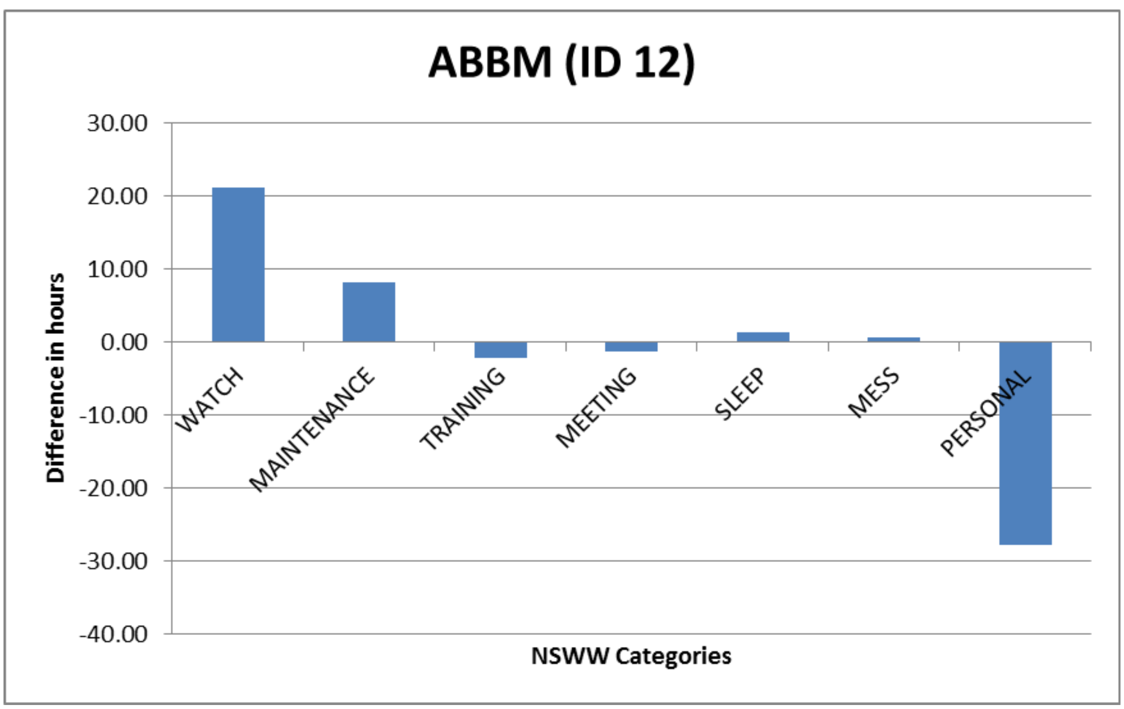


Figure 31. Simulated allocation vs NSWW allocation difference results A ble Seaman Communication Information Systems (ID 13)

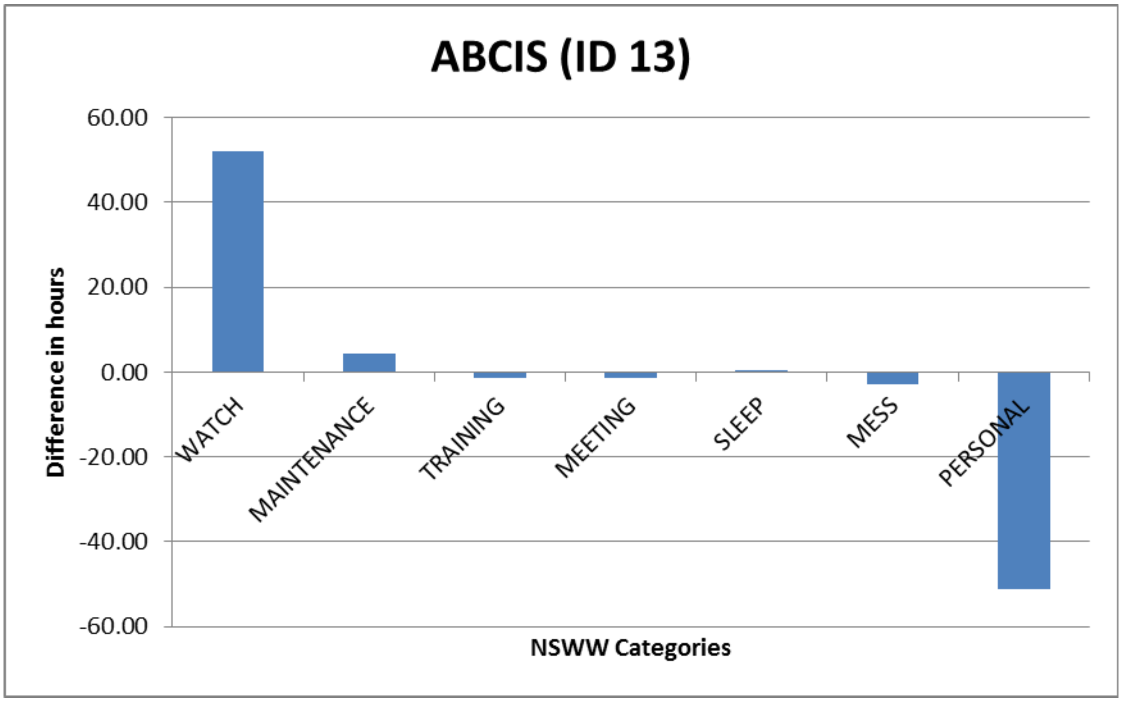


Figure 32. Simulated allocation vs NSWW allocation difference results A ble Seaman Marine Technician (ID 14)

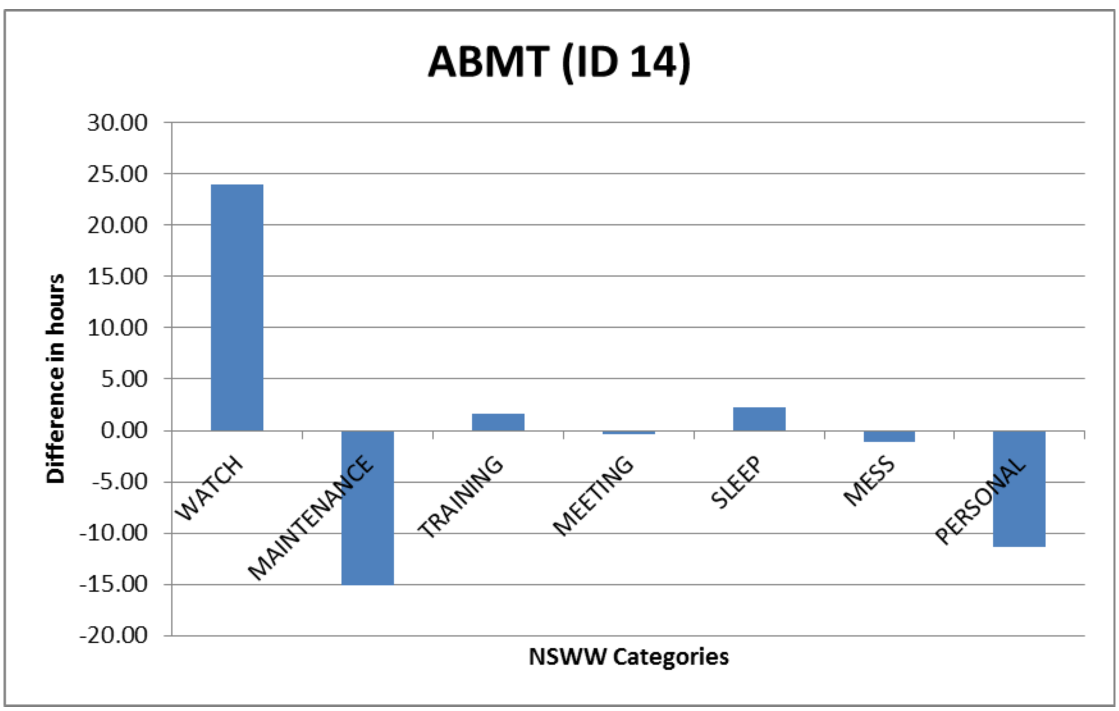


Figure 33. Simulated allocation vs NSWW allocation difference results Able Seaman Electrical Technicians (ID 15)

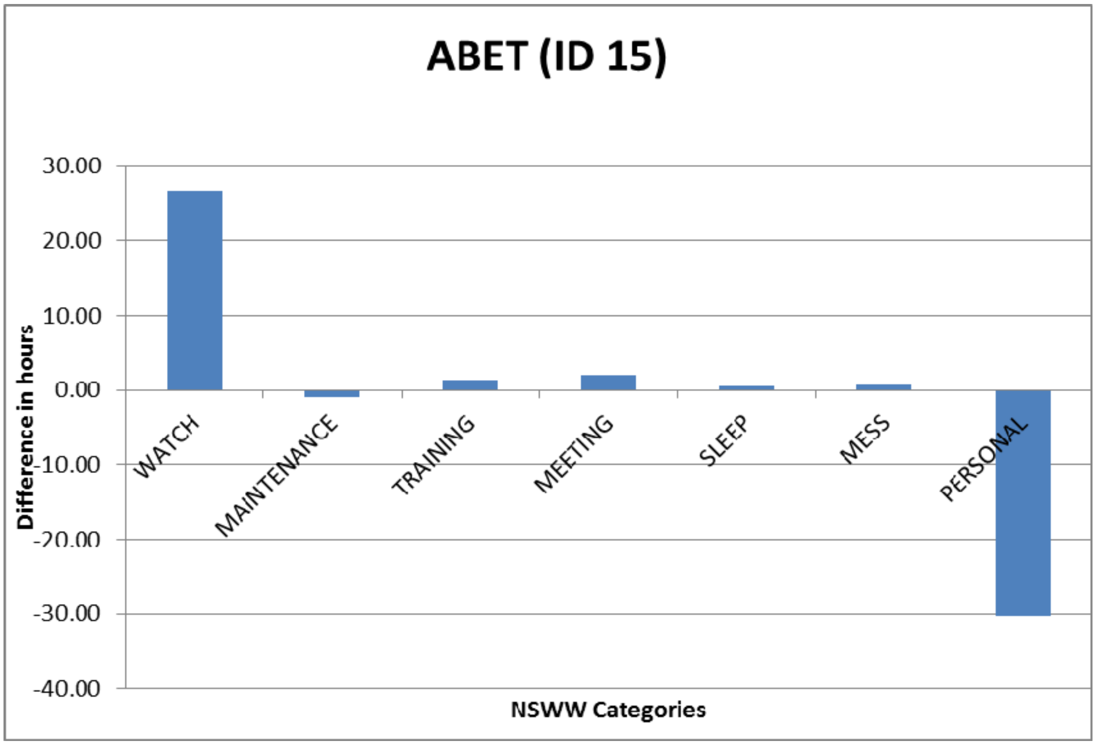


Figure 34. Simulated allocation vs NSWW allocation difference results Able Seaman Marine Technician (ID 16)

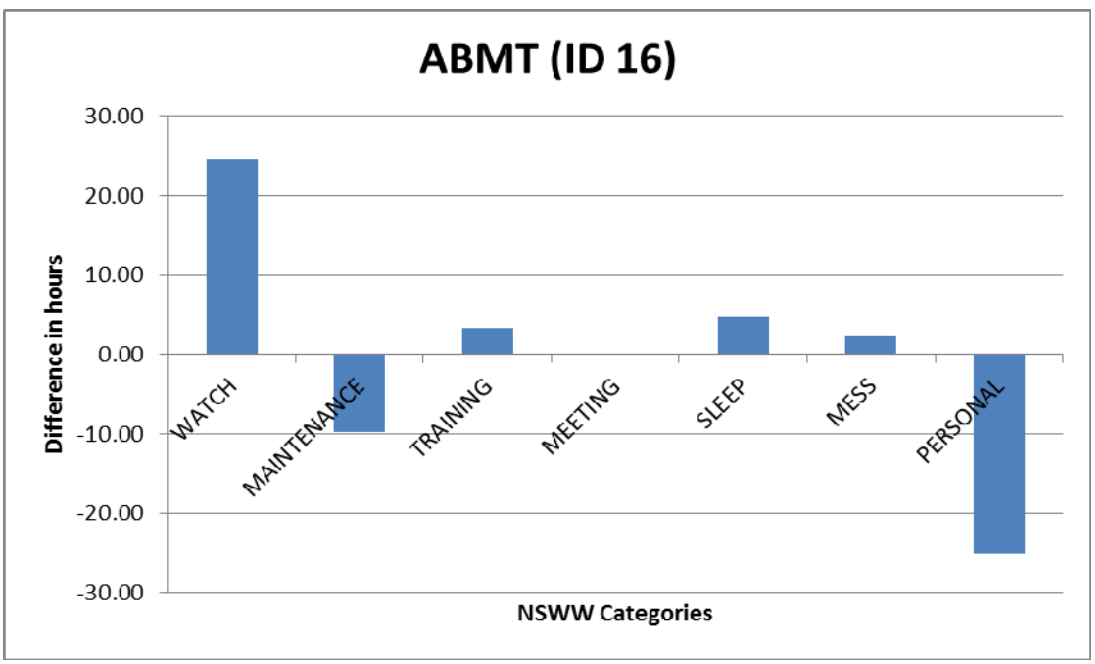


Figure 35. Simulated allocation vs NSWW allocation difference results Able Seaman Cook (ID 17)

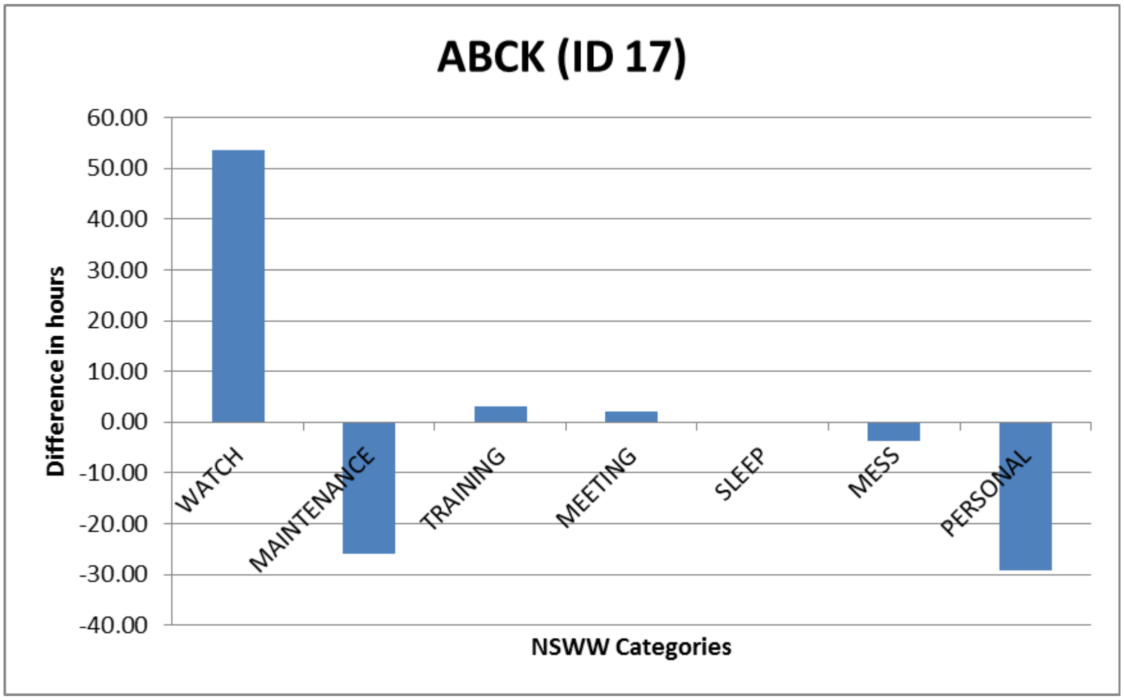


Figure 36. Simulated allocation vs NSWW allocation difference results A ble Seaman Communication Information Systems (ID 18)

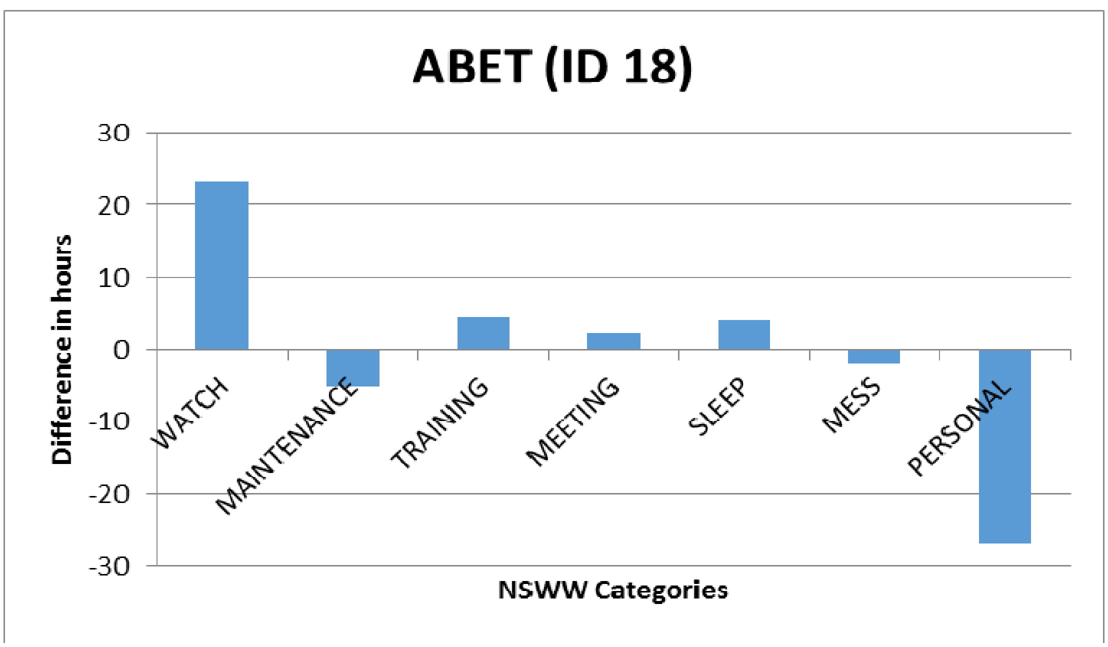


Figure 37. Simulated allocation vs NSWW allocation difference results Leading Seaman Bosun (ID 19)

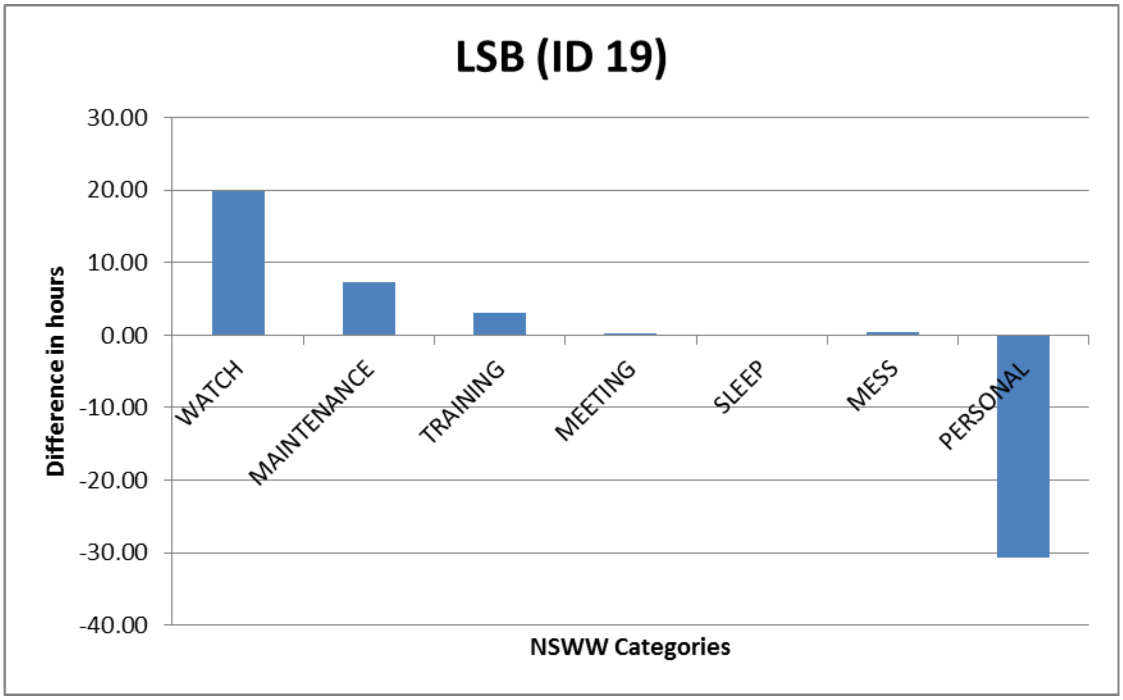


Figure 38. Simulated allocation vs NSWW allocation difference results Able Seaman Bosun's Mate (ID 20)

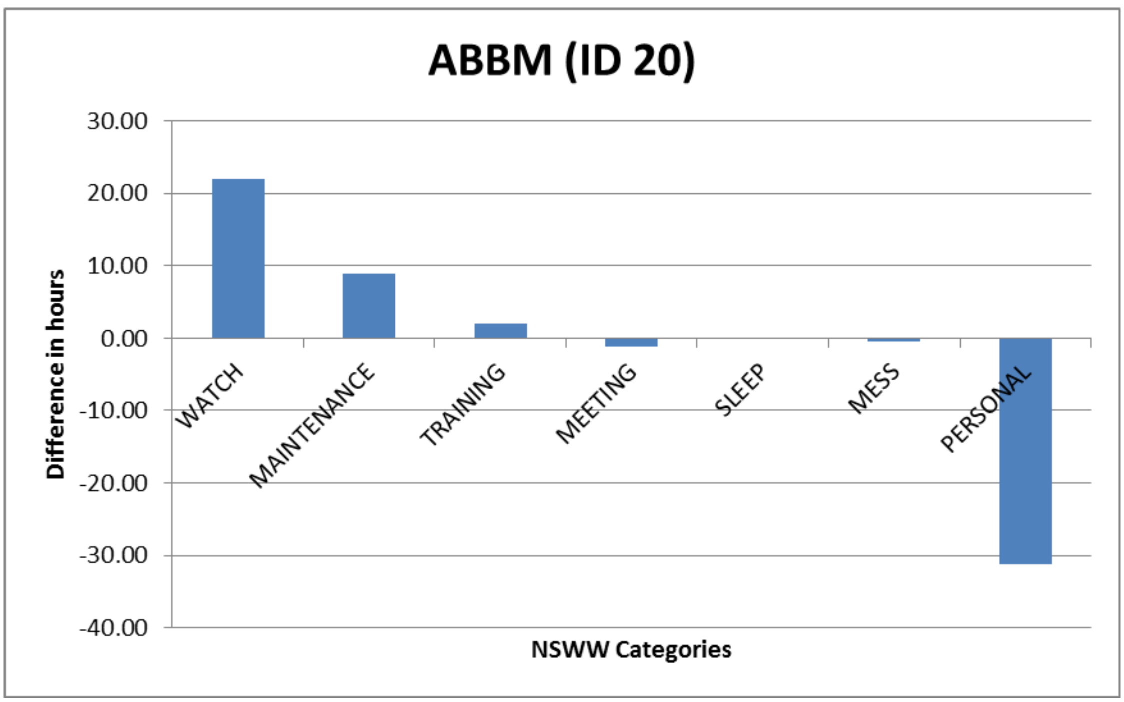
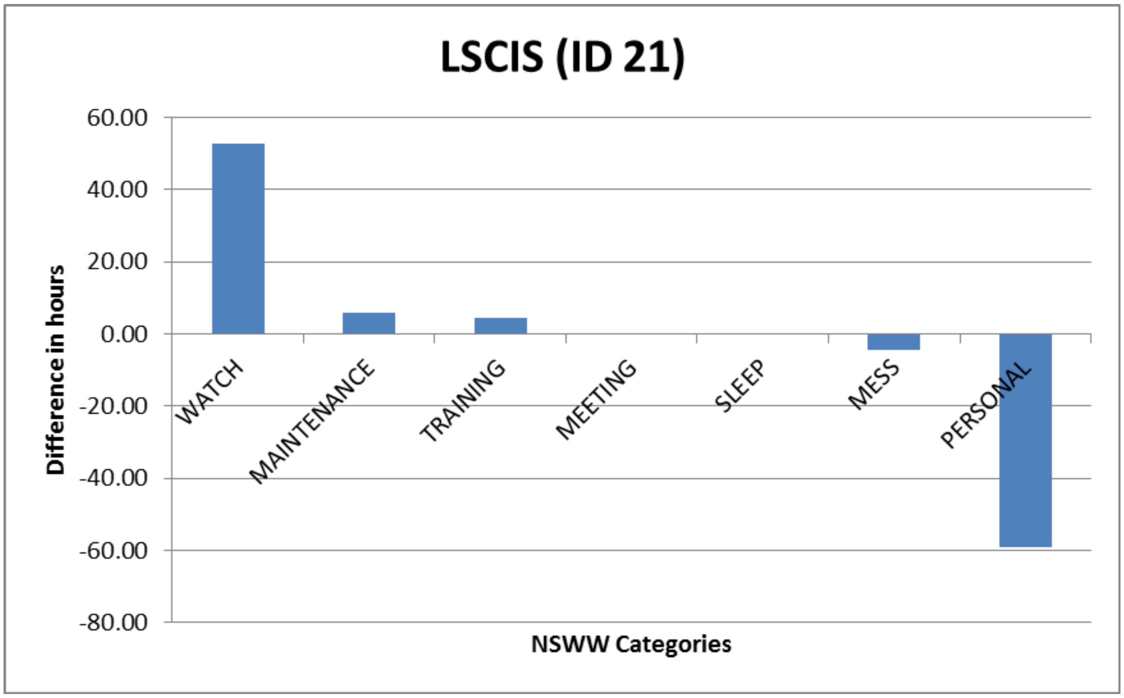


Figure 39. Simulated allocation vs NSWW allocation difference results Leading Seaman Communication Information Systems (ID 21)



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APPENDIX D. SIMULATED FAST (8 AND 6 HOUR SLEEP WITH LAPSE INDEX)

Figure 40. FAST Simulation—Commanding Officer, 8 hrs sleep with lapse index

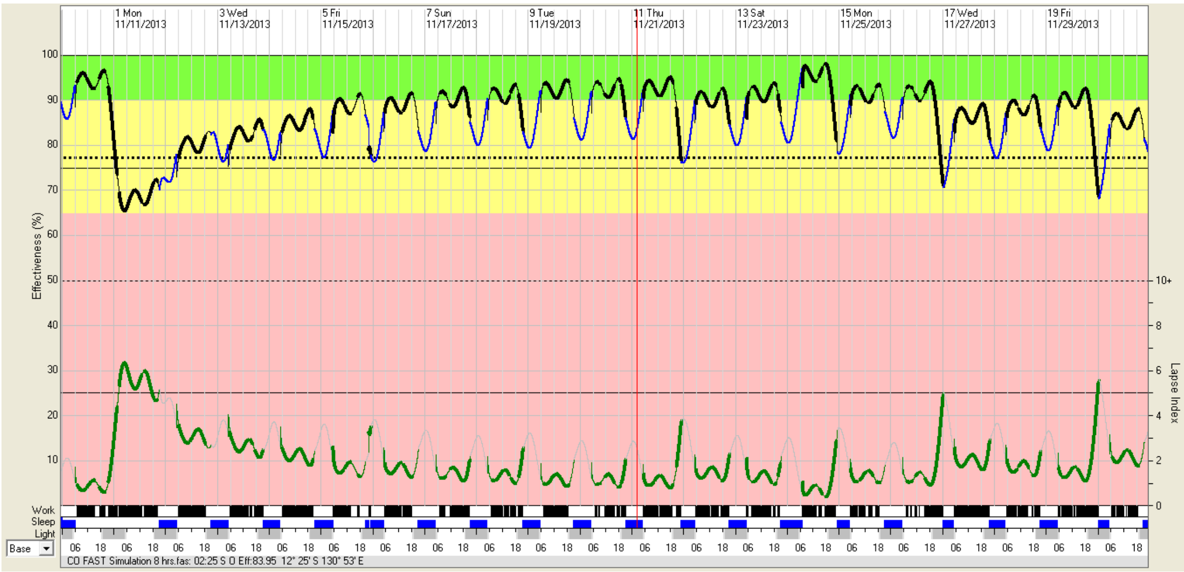


Figure 41. FAST Simulation—Commanding Officer, 6 hrs sleep with lapse index

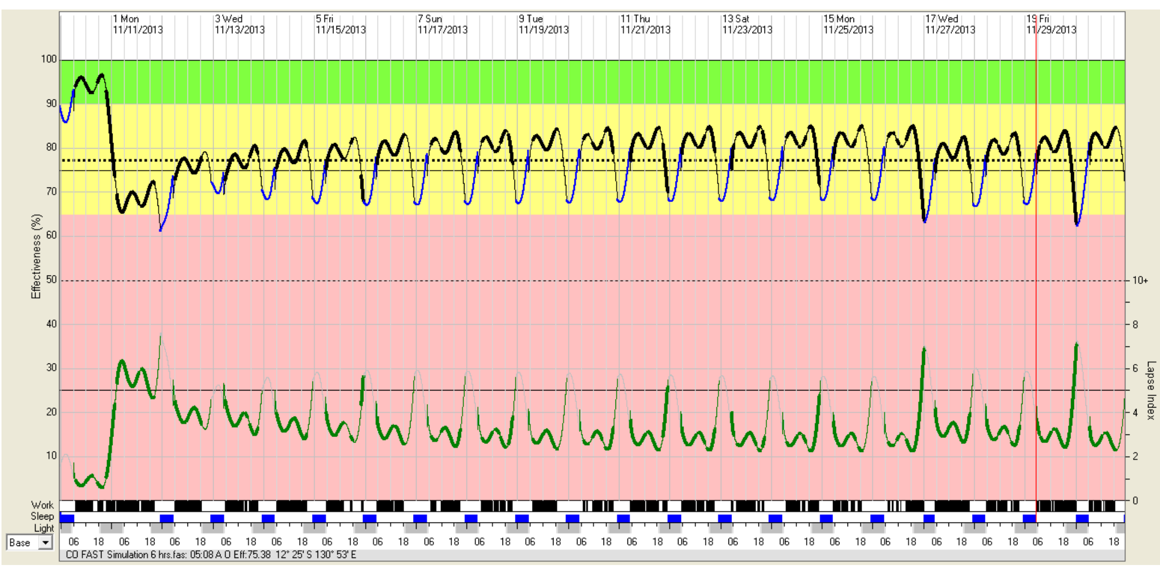


Figure 42. FAST Simulation—Executive Officer, 8 hrs sleep with lapse index

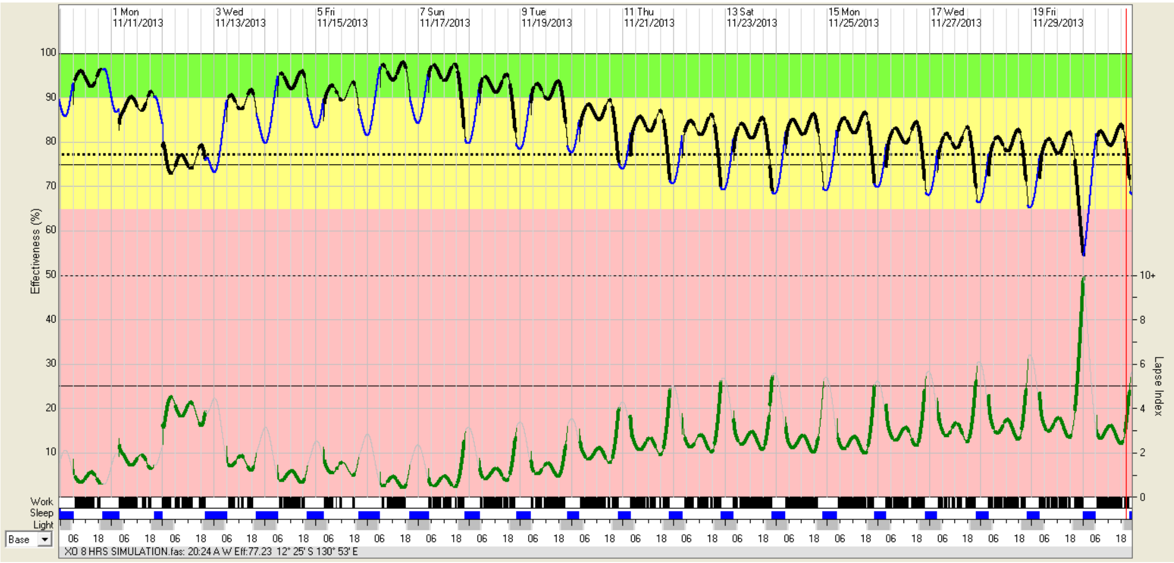


Figure 43. FAST Simulation—Executive Officer, 6 hrs sleep with lapse index

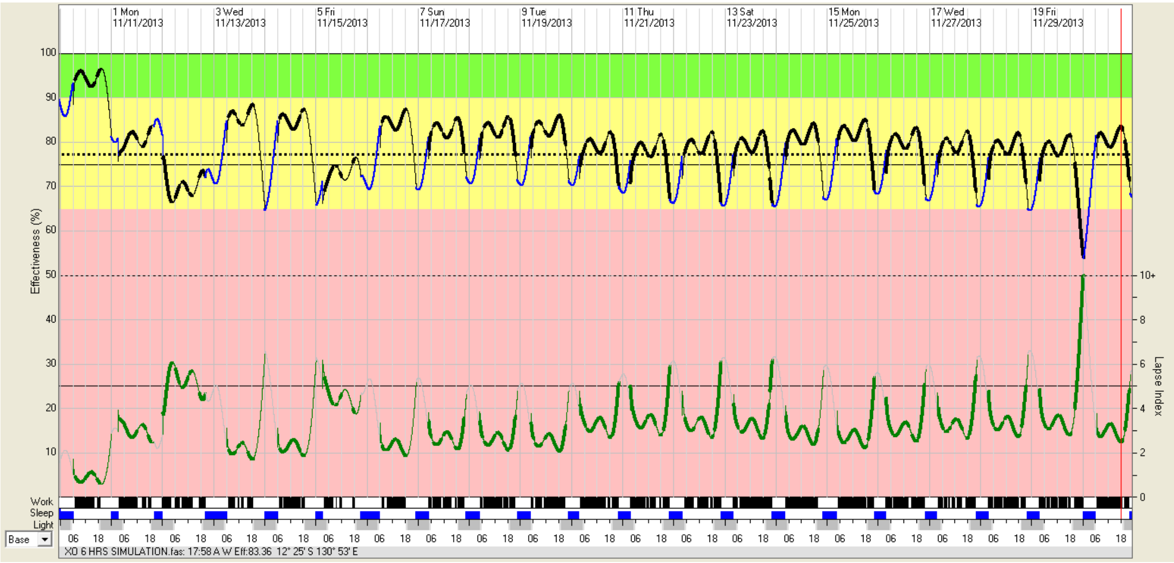


Figure 44. FAST Simulation—Navigator, 8 hrs sleep with lapse index

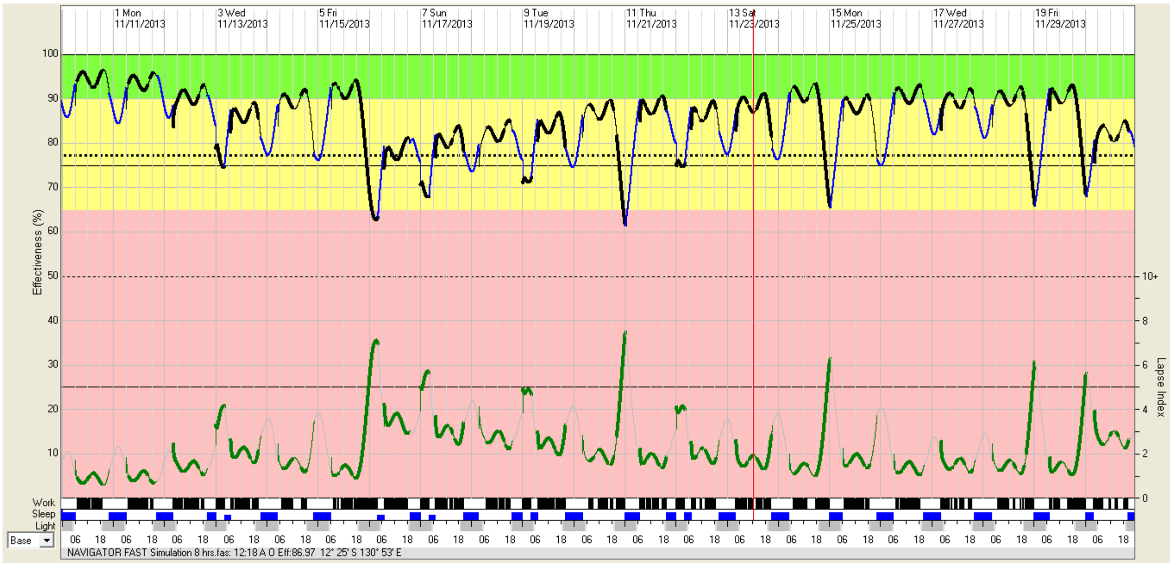


Figure 45. FAST Simulation—Navigator, 6 hrs sleep with lapse index

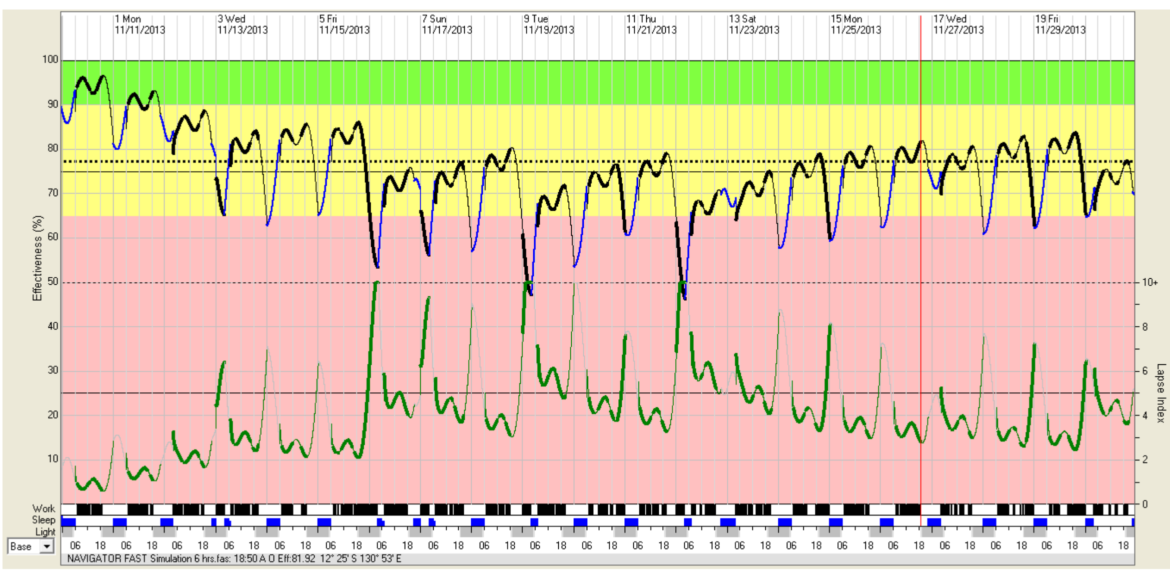


Figure 46. FAST Simulation—Chief Petty Officer (Senior Technical), 8 hrs sleep with lapse index

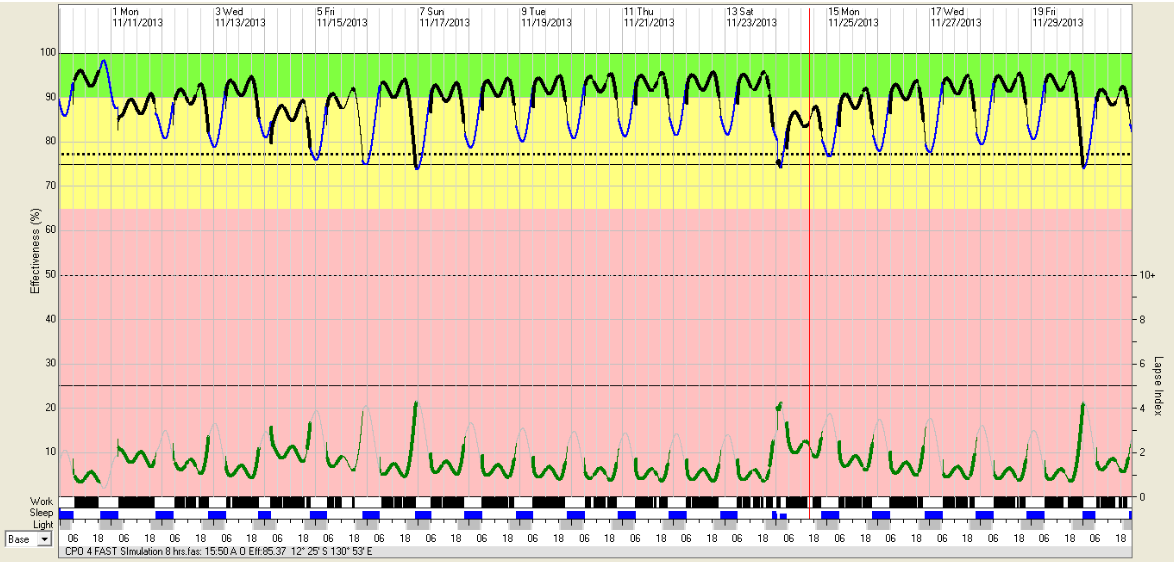


Figure 47. FAST Simulation—Chief Petty Officer (Senior Technical), 6 hrs sleep with lapse index

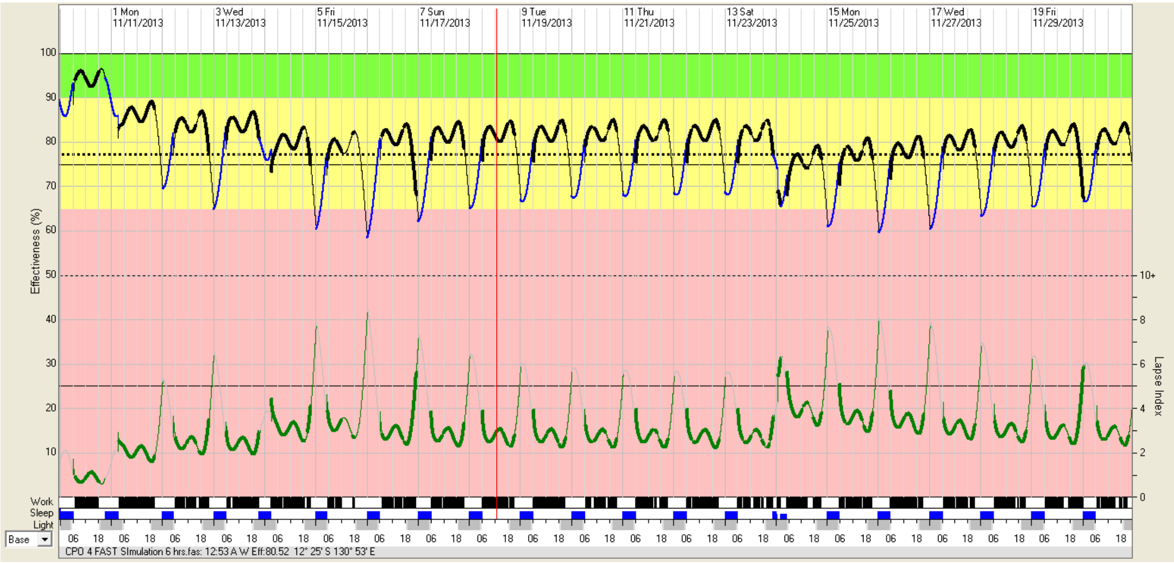


Figure 48. FAST Simulation—Petty Officer (Naval Police Coxswain), 8 hrs sleep with lapse index

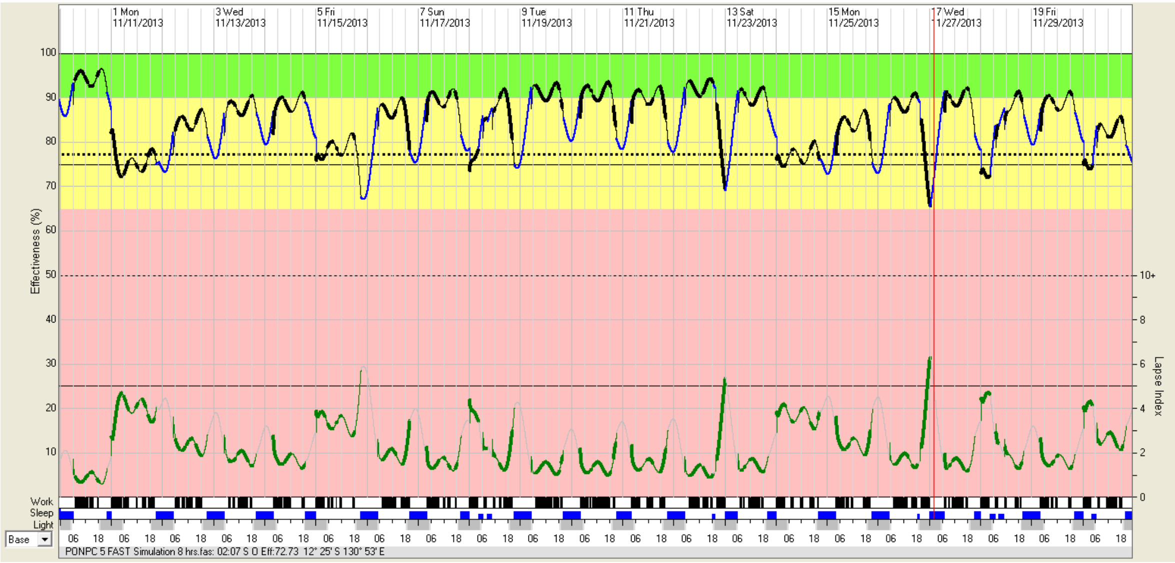


Figure 49. FAST Simulation—Petty Officer (Naval Police Coxswain), 8 hrs sleep with lapse index

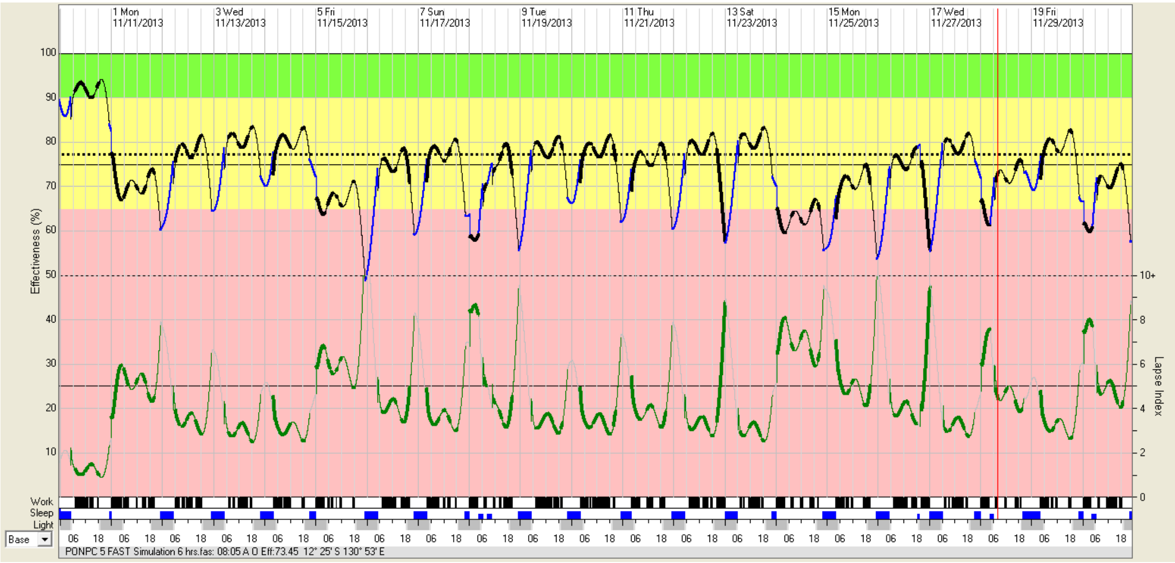


Figure 50. FAST Simulation—Petty Officer (Boatswain), 8 hrs sleep with lapse index

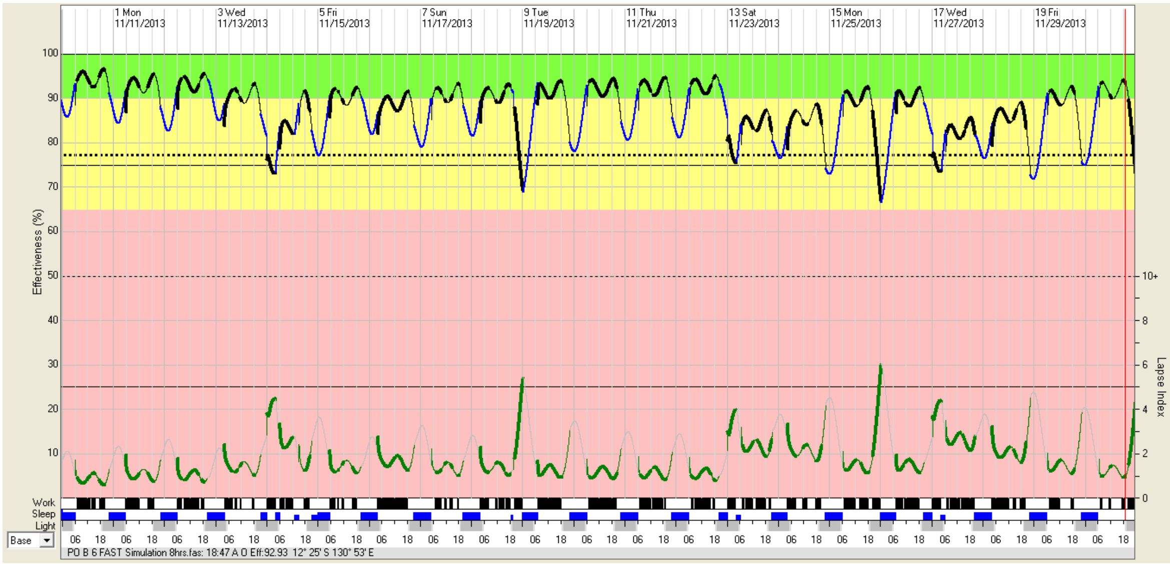


Figure 51. FAST Simulation—Petty Officer (Boatswain), 6 hrs sleep with lapse index

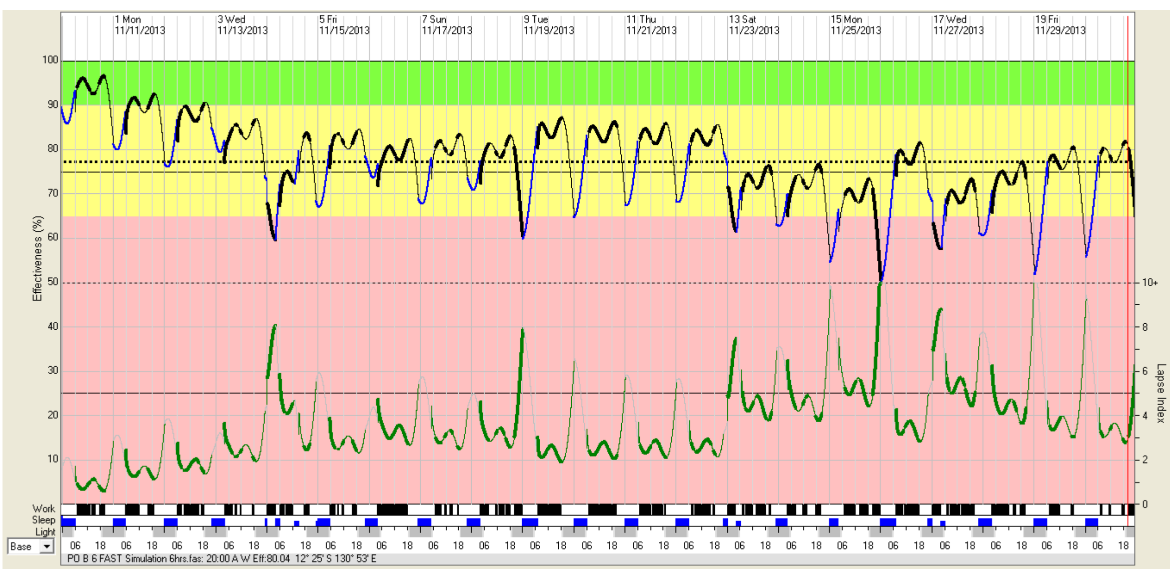


Figure 52. FAST Simulation—Leading Seaman (Boatswain), 8 hrs sleep with lapse index

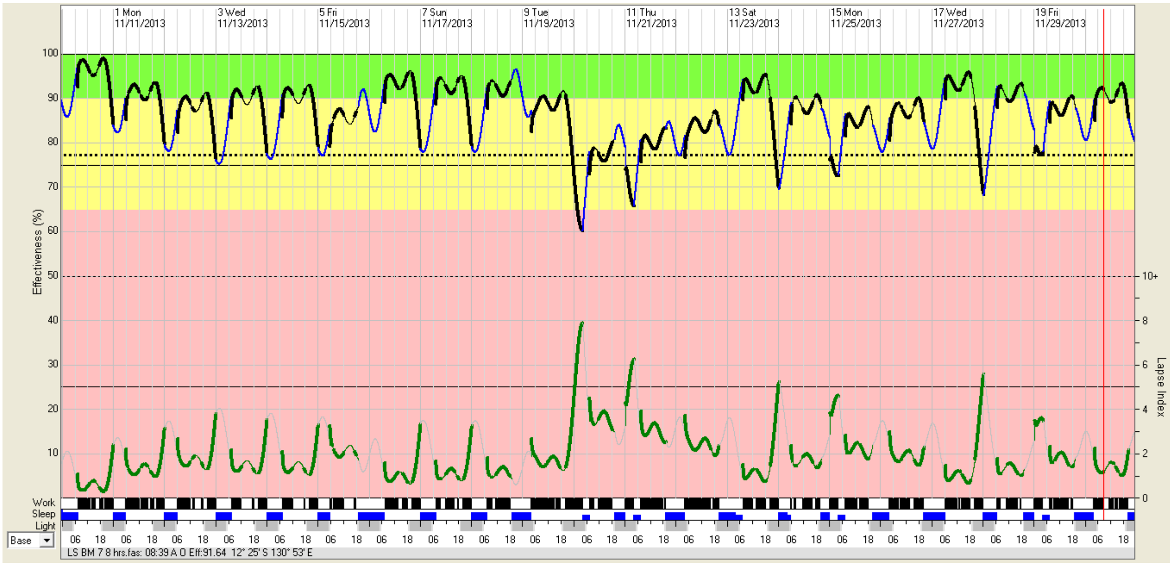


Figure 53. FAST Simulation—Leading Seaman (Boatswain), 6 hrs sleep with lapse index

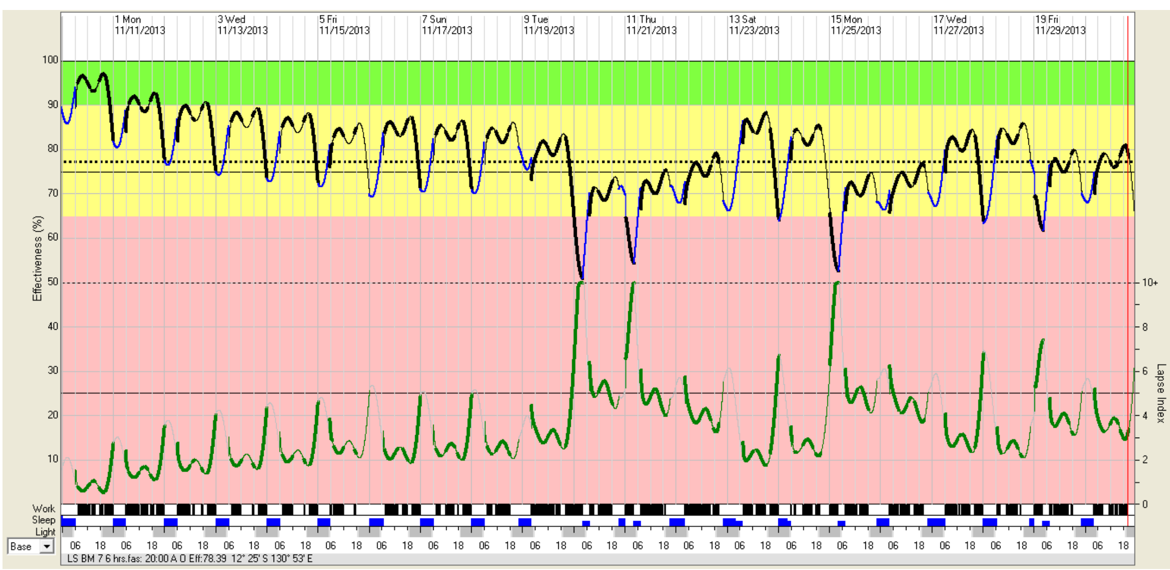


Figure 54. FAST Simulation—Leading Seaman (Cook), 8 hrs sleep with lapse index

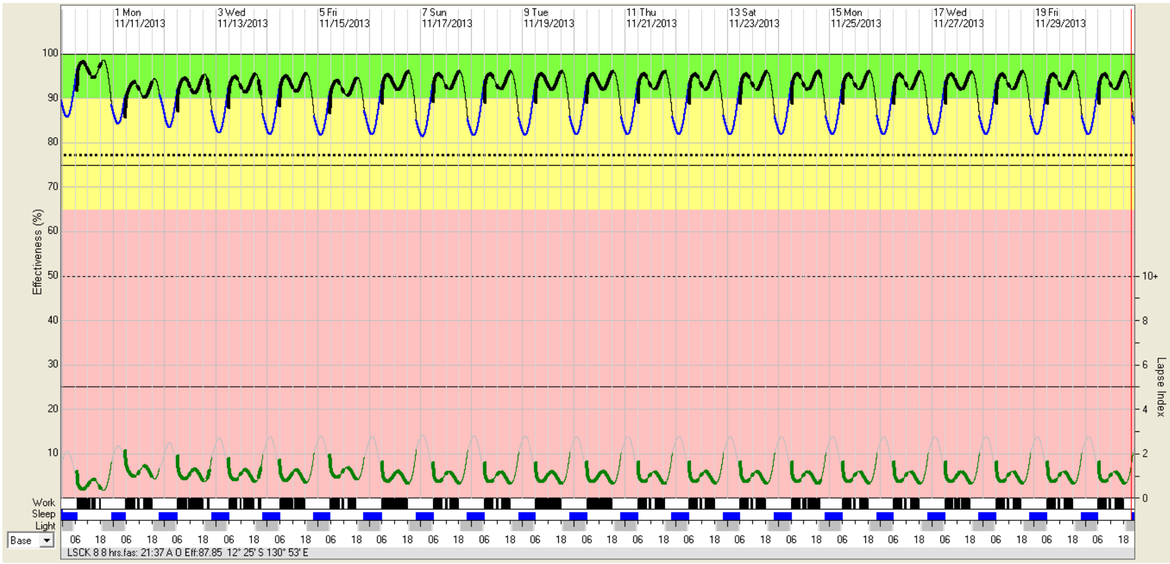


Figure 55. FAST Simulation—Leading Seaman (Cook), 6 hrs sleep with lapse index

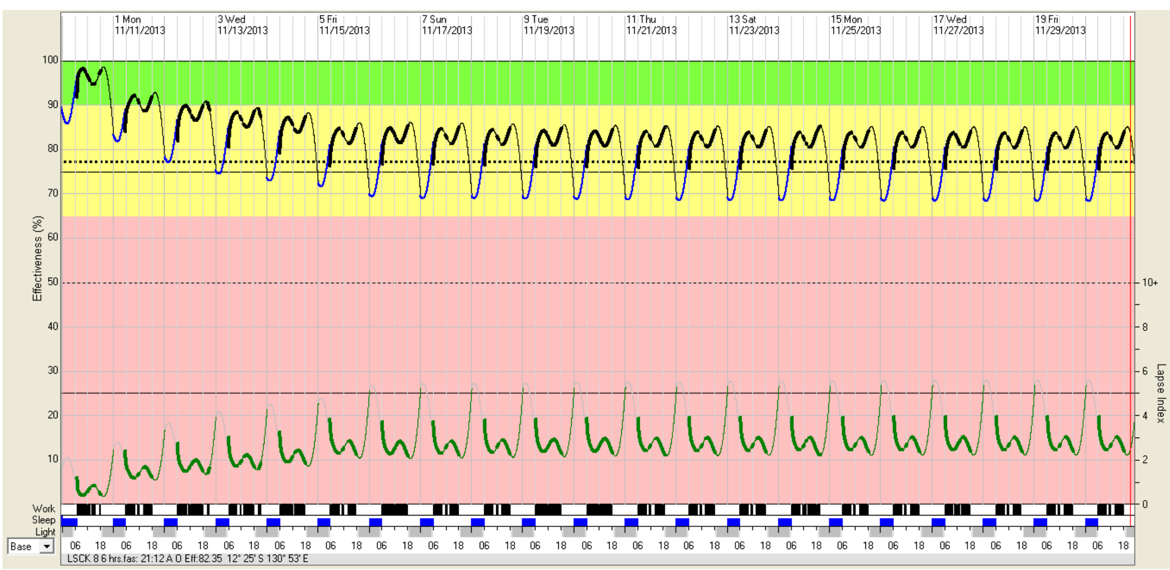


Figure 56. FAST Simulation—Leading Seaman (Electrical Technician), 8 hrs sleep with lapse index

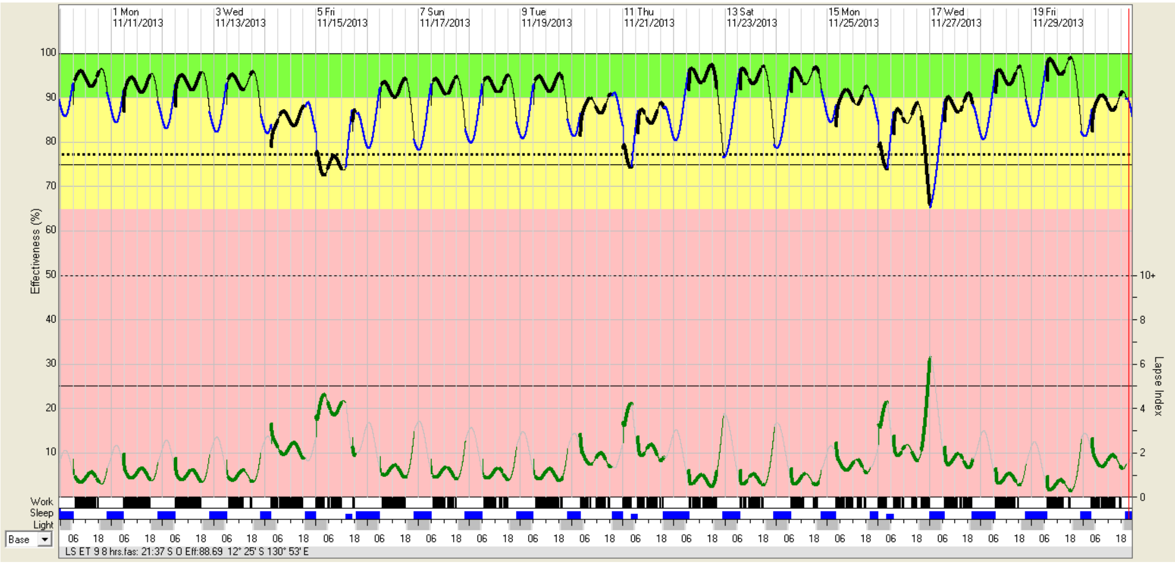


Figure 57. FAST Simulation—Leading Seaman (Electrical Technician), 6 hrs sleep with lapse index

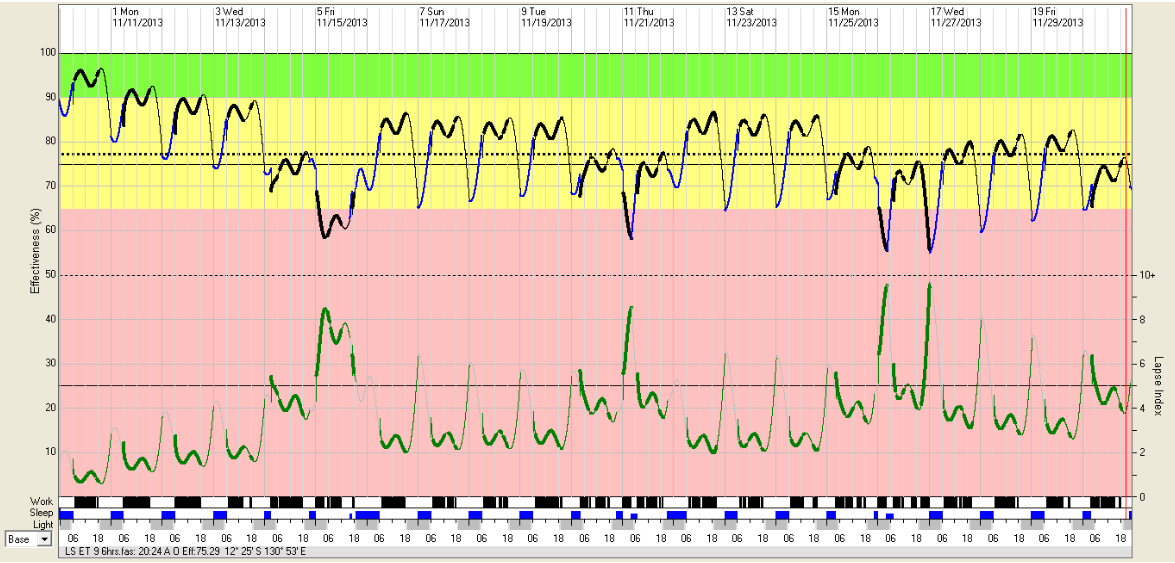


Figure 58. FAST Simulation—Able Seaman (Bosuns Mate), 8 hrs sleep with lapse index

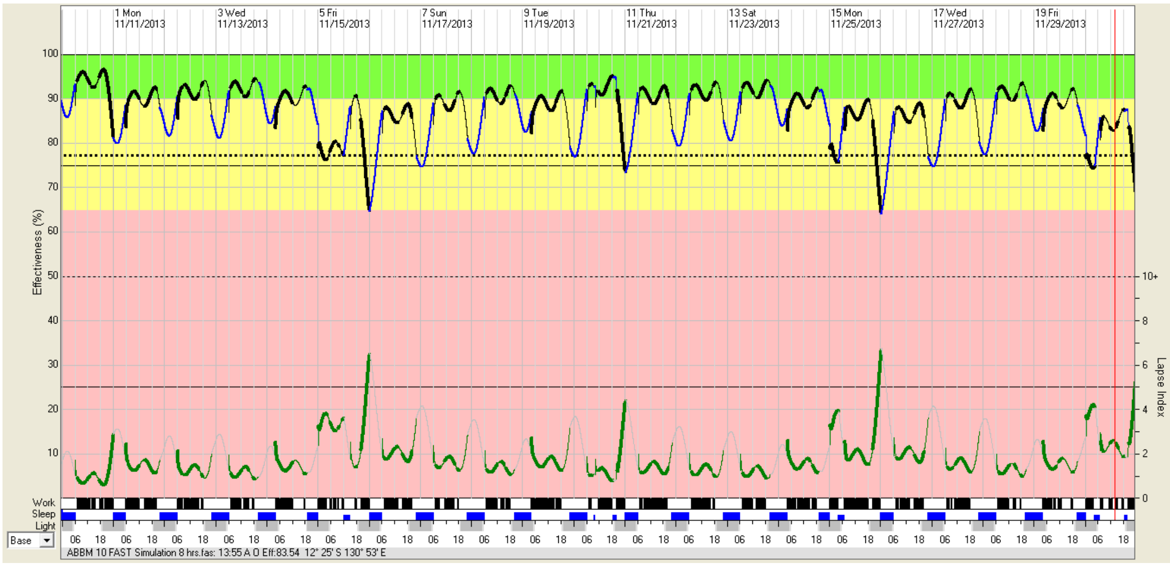


Figure 59. FAST Simulation— Able Seaman (Bosuns Mate), 6 hrs sleep with lapse index

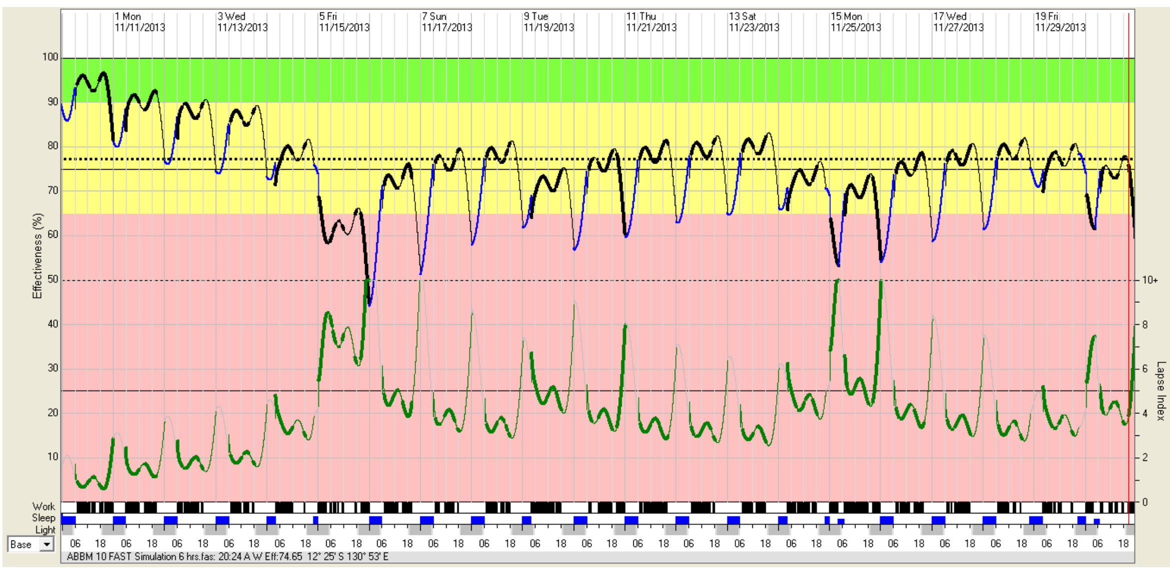


Figure 60. FAST Simulation— Able Seaman (Bosuns Mate), 8 hrs sleep with lapse index

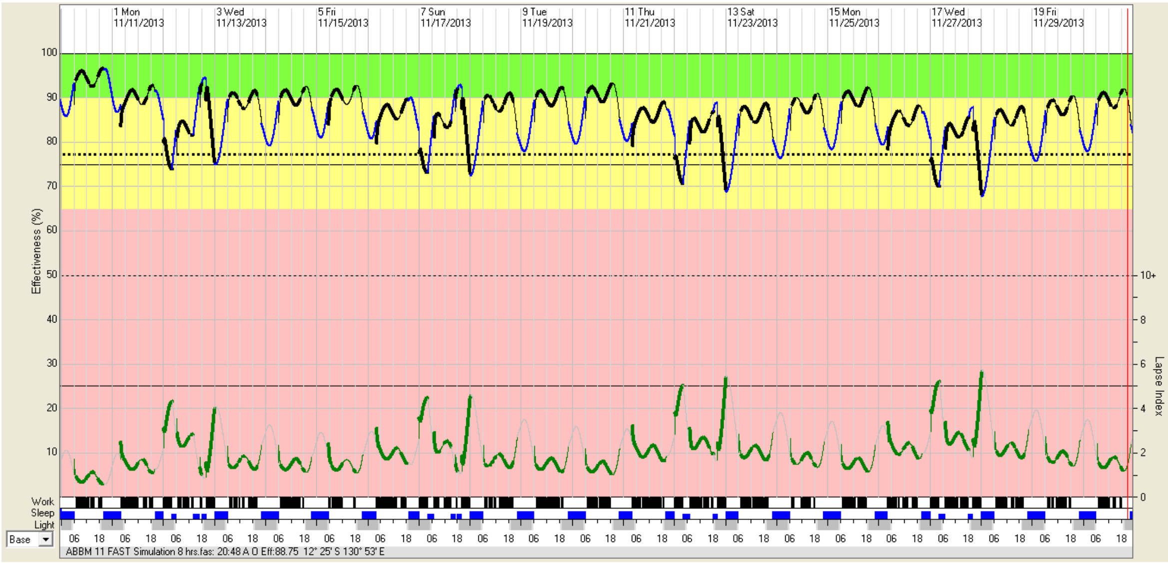


Figure 61. FAST Simulation— Able Seaman (Bosuns Mate), 6 hrs sleep with lapse index

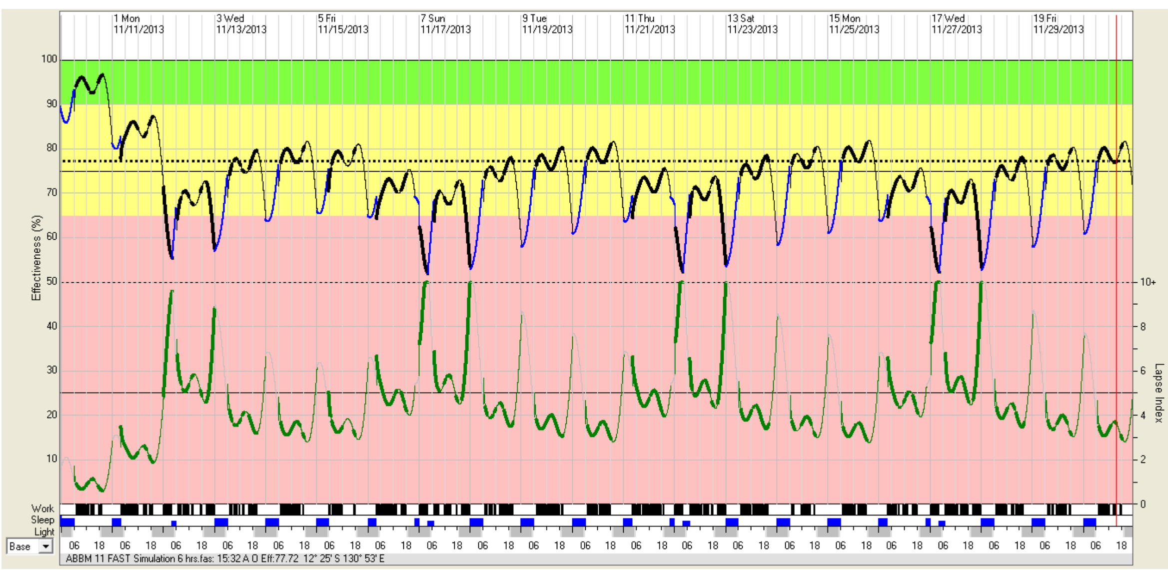


Figure 62. FAST Simulation—Able Seaman (Bosuns Mate), 8 hrs sleep with lapse index

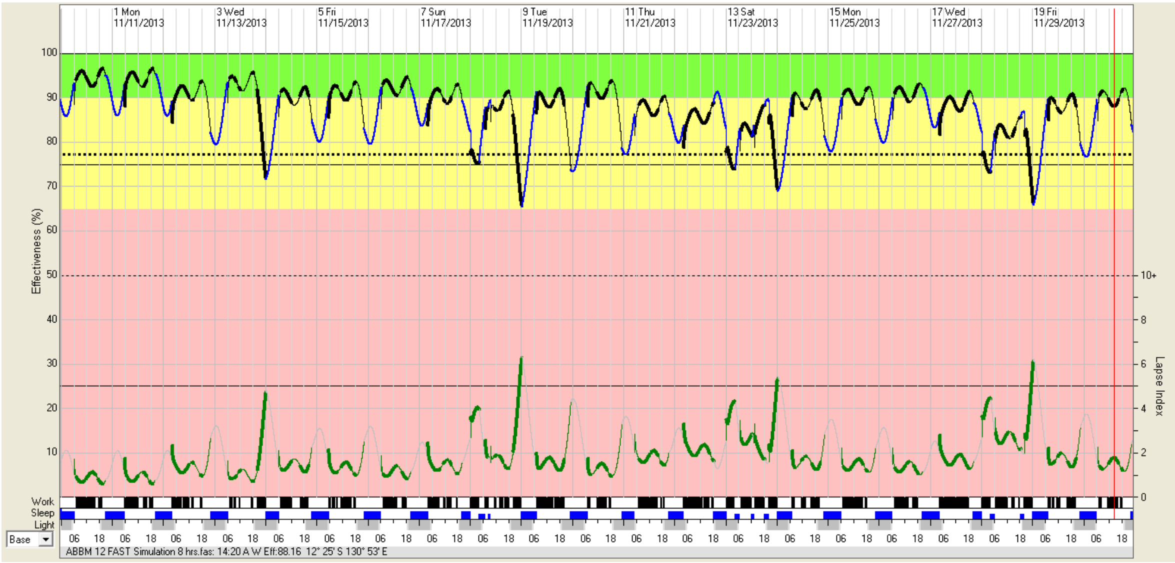


Figure 63. FAST Simulation—Able Seaman (Bosuns Mate), 6 hrs sleep with lapse index

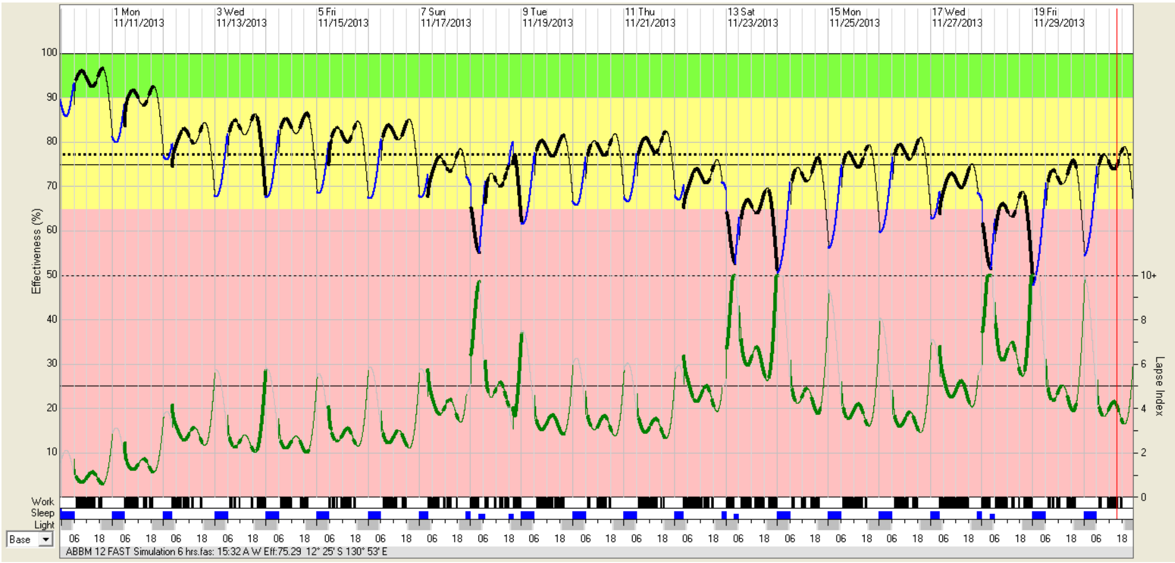


Figure 64. FAST Simulation—Able Seaman (CIS), 8 hrs sleep with lapse index

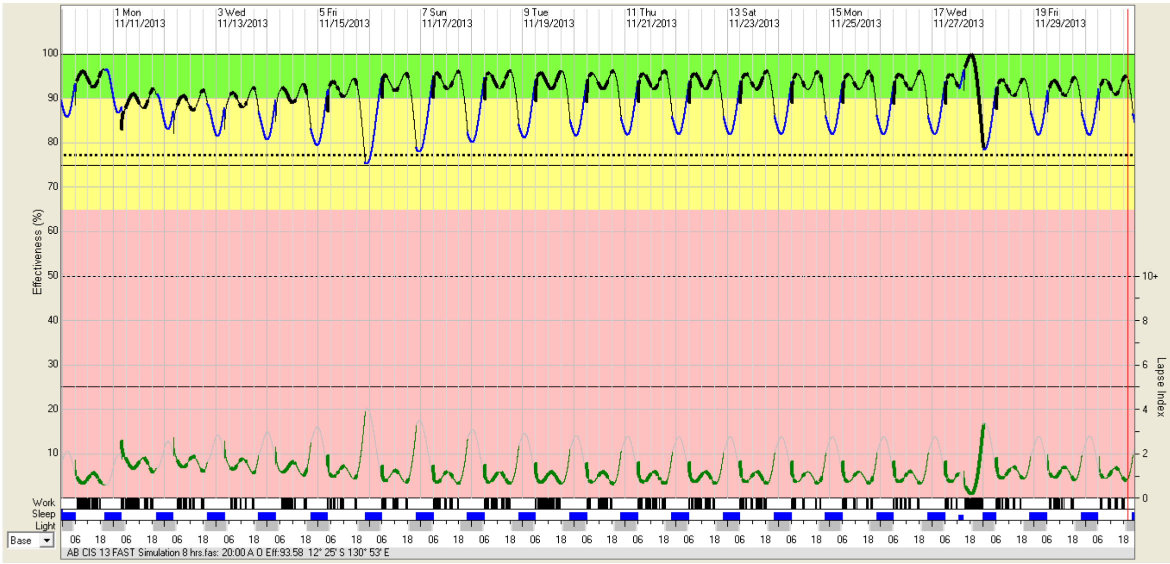


Figure 65. FAST Simulation—Able Seaman (CIS), 6 hrs sleep with lapse index

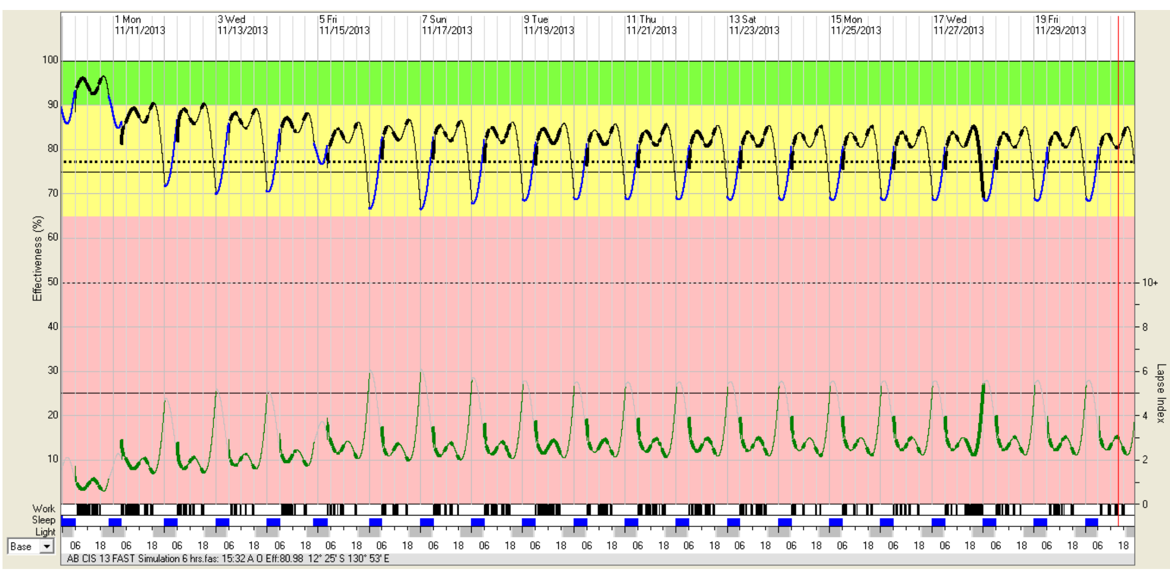


Figure 66. FAST Simulation—Able Seaman (Marine Technician), 8 hrs sleep with lapse index

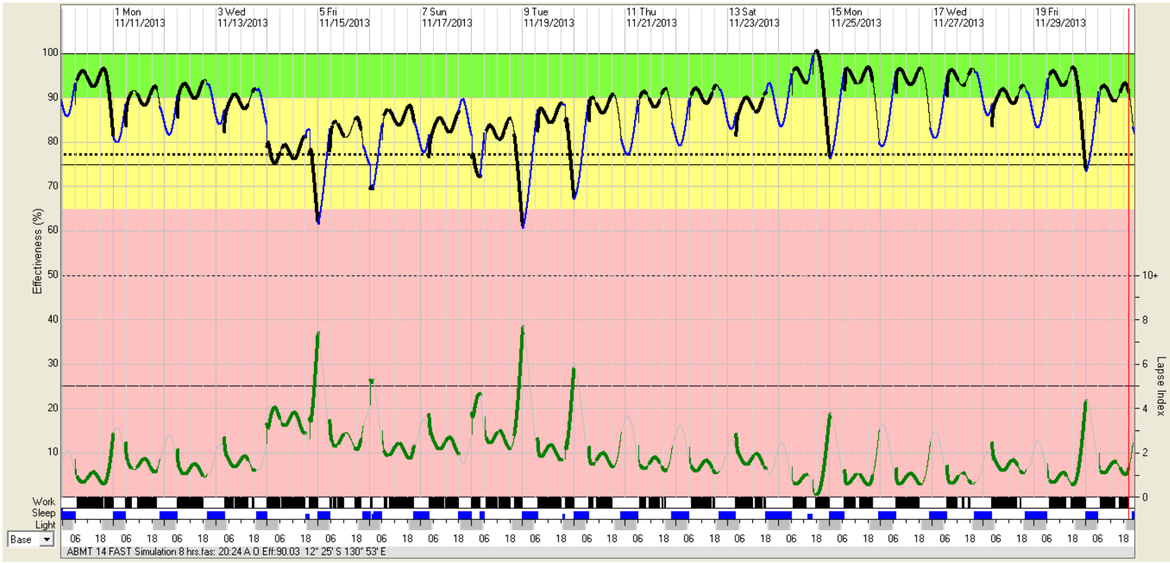


Figure 67. FAST Simulation—Able Seaman (Marine Technician), 6 hrs sleep with lapse index

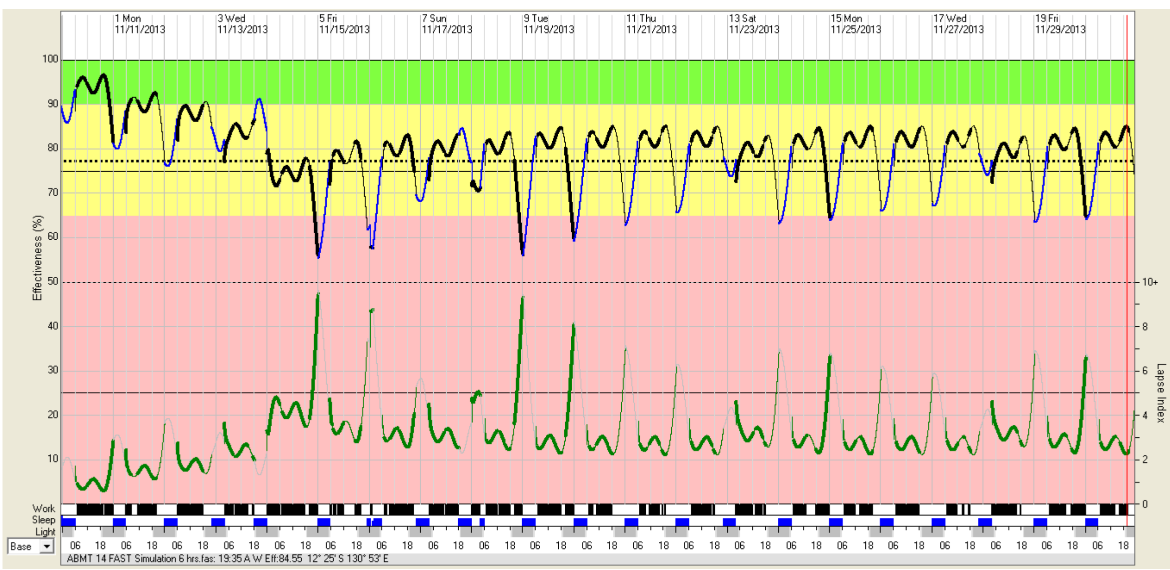


Figure 68. FAST Simulation—Able Seaman (Electrical Technician), 8 hrs sleep with lapse index

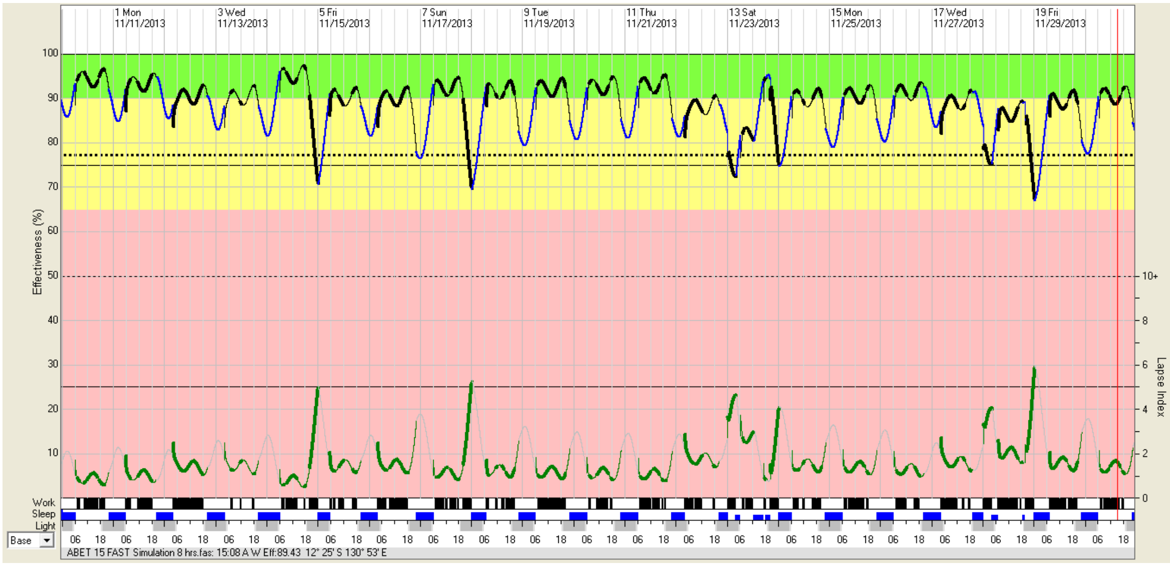


Figure 69. FAST Simulation—Able Seaman (Electrical Technician),

Figure 70. 6 hrs sleep with lapse index

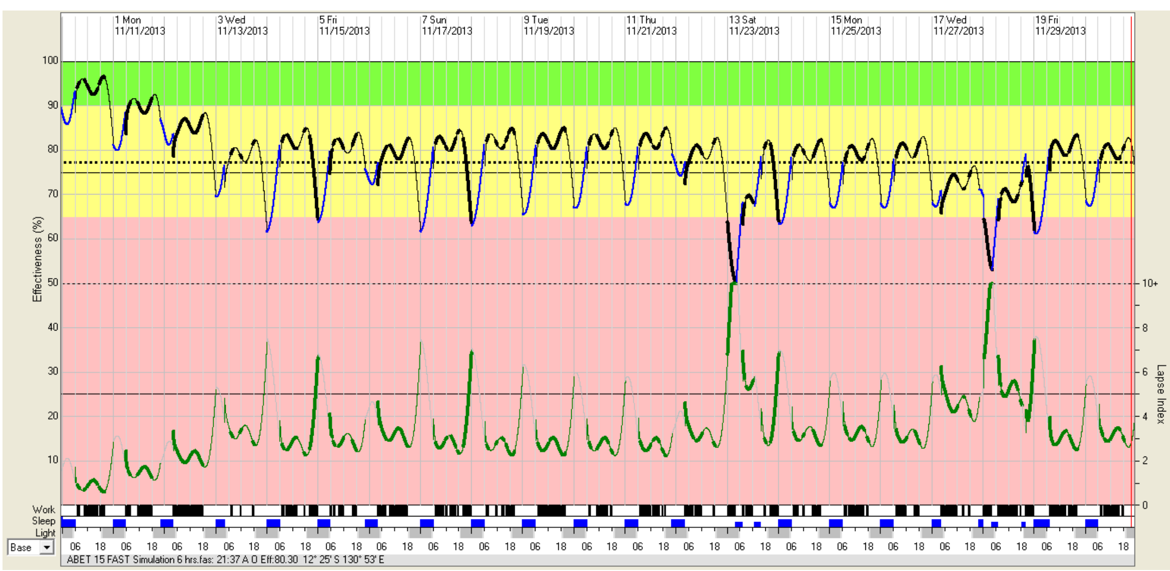


Figure 71. FAST Simulation—Able Seaman (Marine Technician), 8 hrs sleep with lapse index

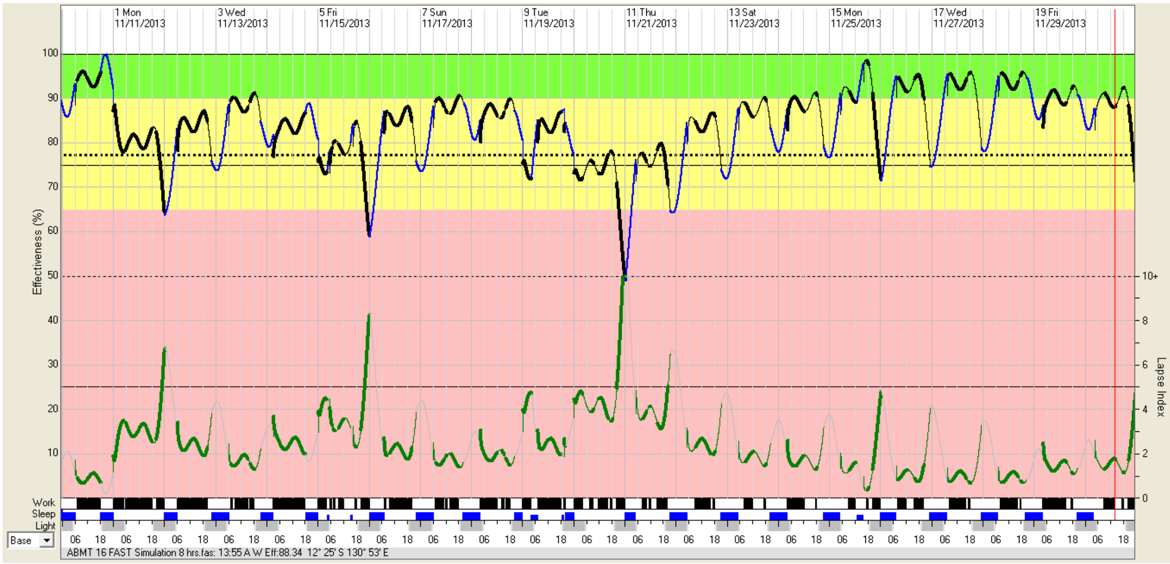


Figure 72. FAST Simulation—Able Seaman (Marine Technician), 6 hrs sleep with lapse index

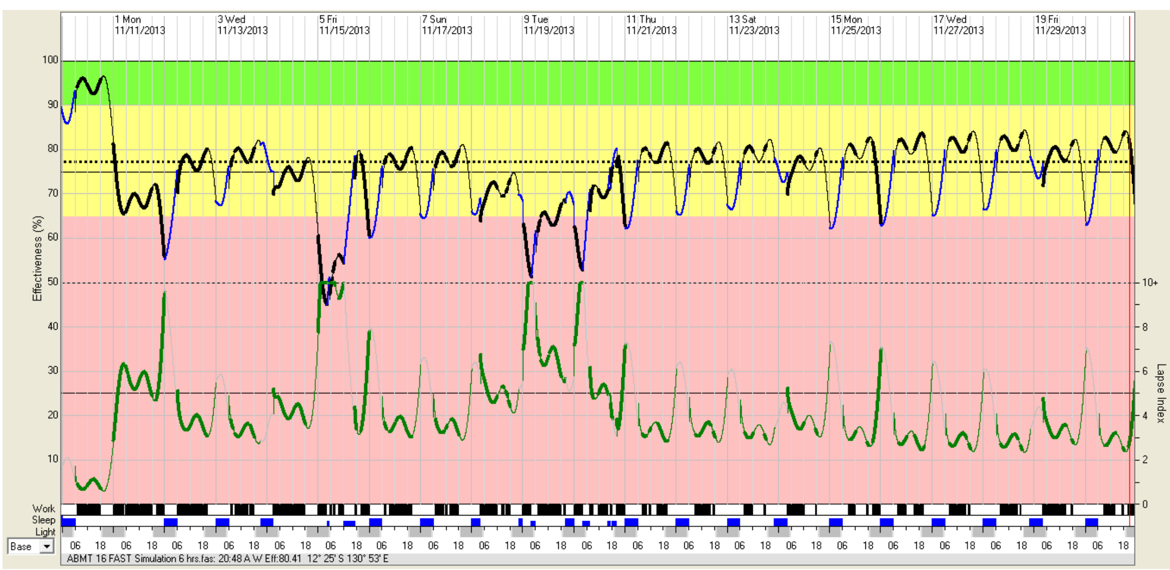


Figure 73. FAST Simulation—Able Seaman (Cook), 8 hrs sleep with lapse index

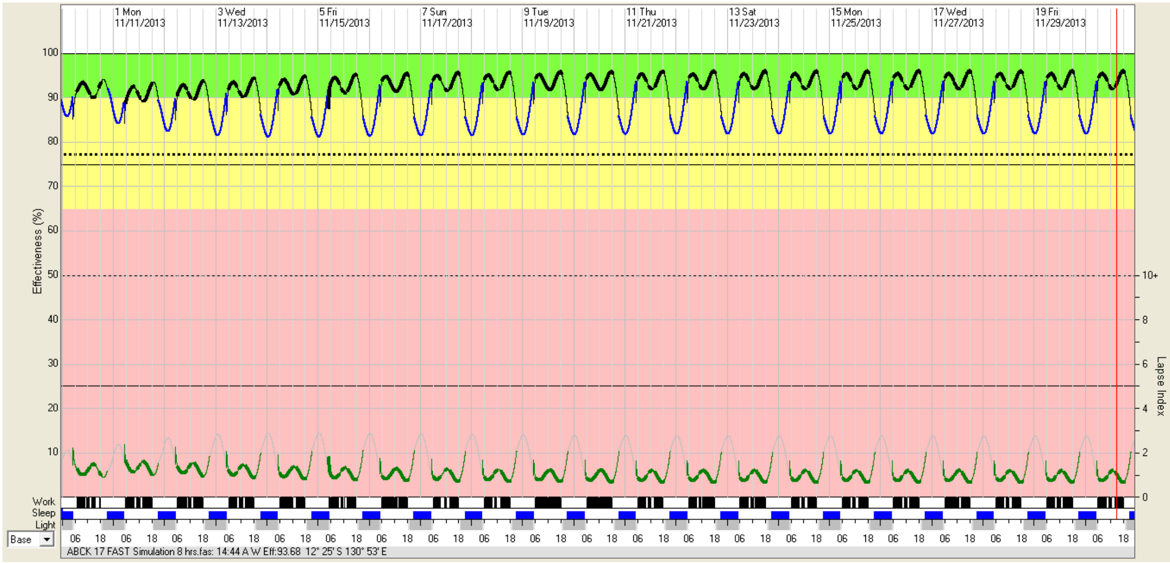


Figure 74. FAST Simulation—Able Seaman (Cook), 6 hrs sleep with lapse index

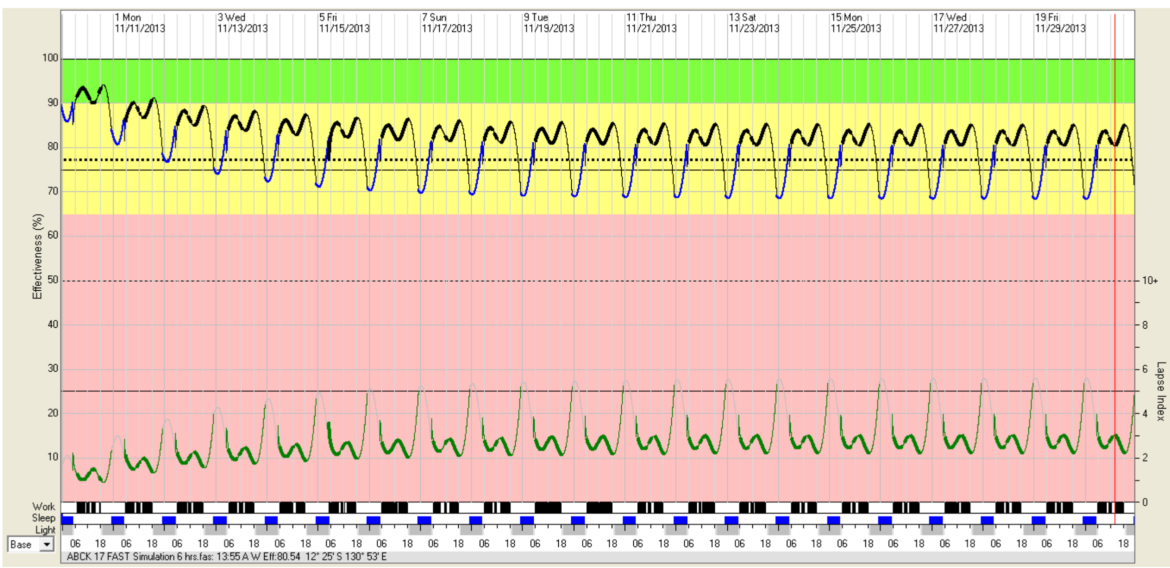


Figure 75. FAST Simulation—Able Seaman (Electrical Technician 18), 8 hrs sleep with lapse index

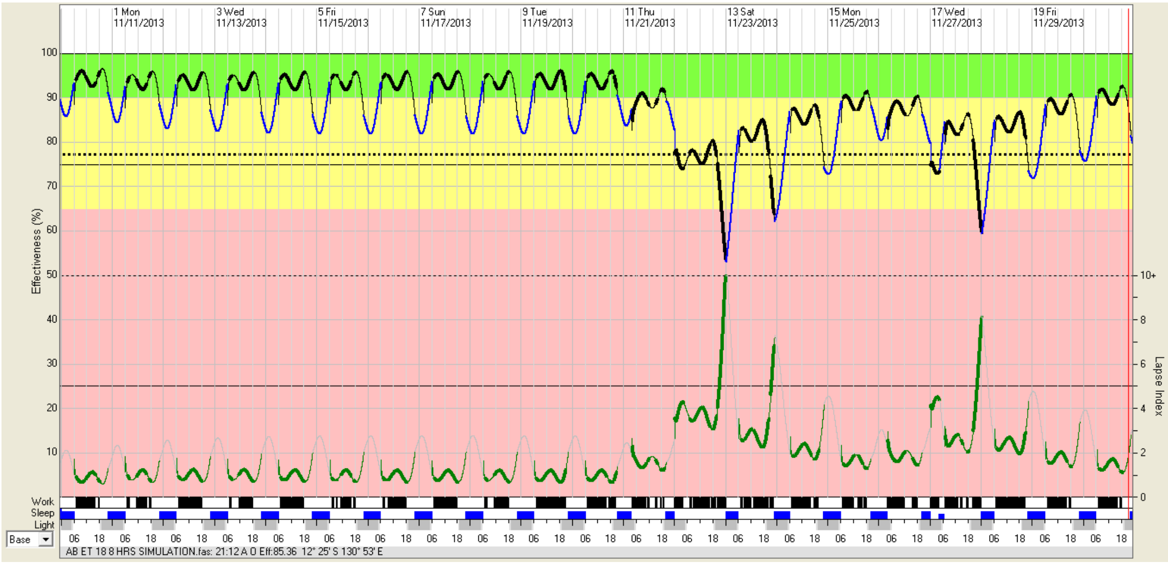


Figure 76. FAST Simulation—Able Seaman (Electrical Technician 18), 6 hrs sleep with lapse index

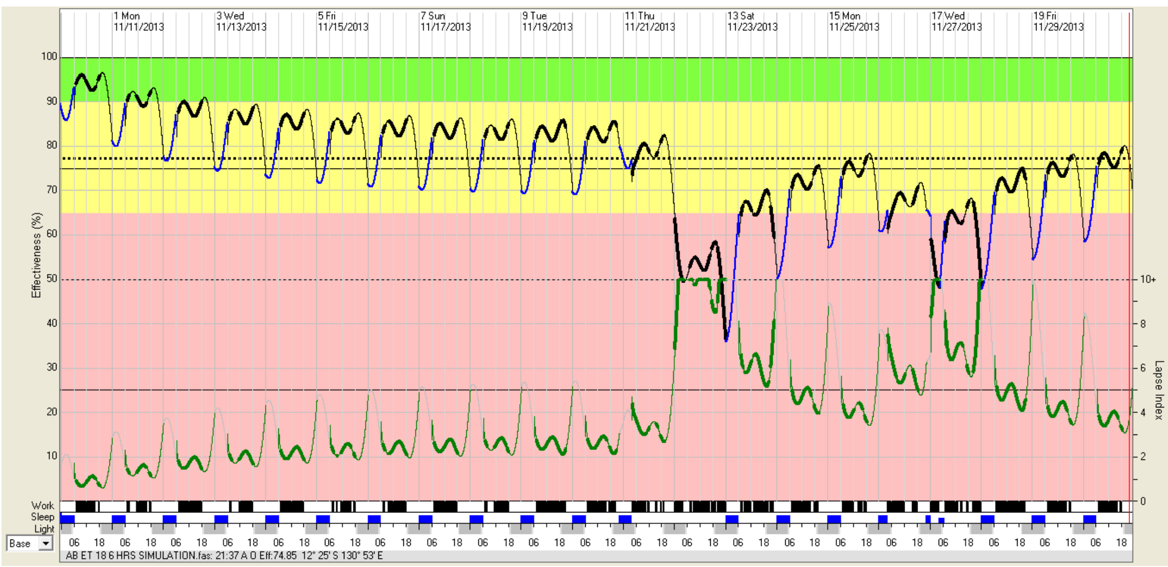


Figure 77. FAST Simulation—Leading Seaman (Bosun 19), 6 hrs sleep with lapse index

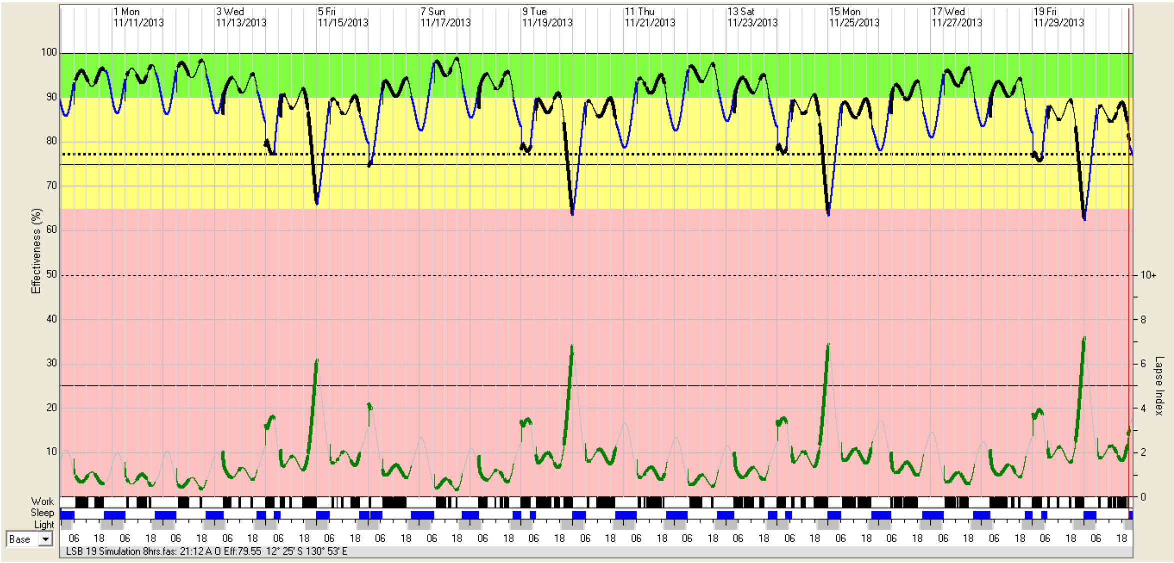


Figure 78. FAST Simulation—Leading Seaman (Bosun 19), 6 hrs sleep with lapse index

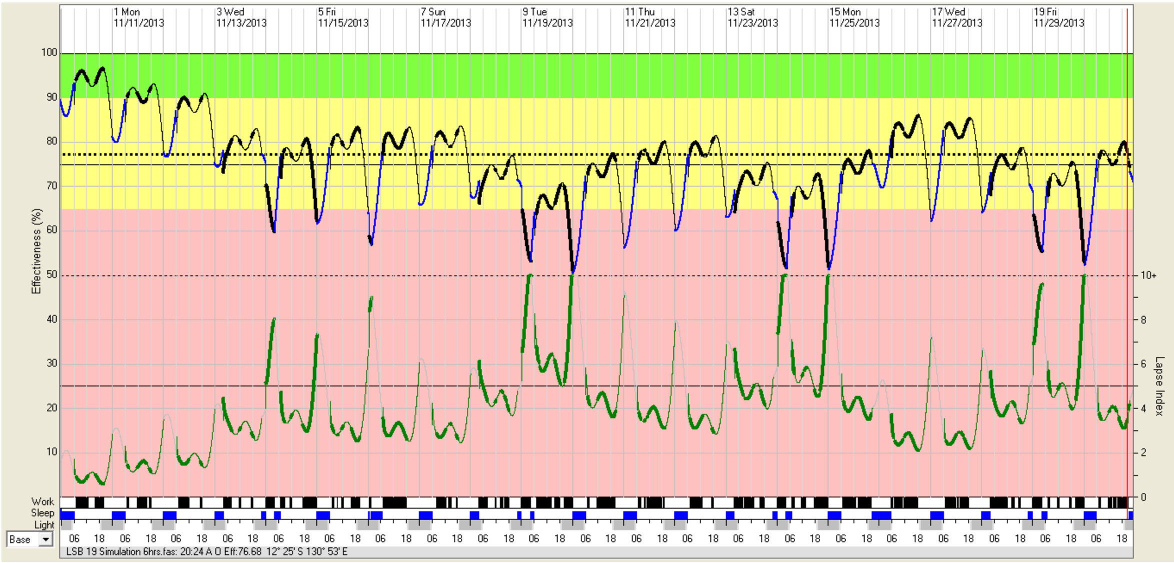


Figure 79. FAST Simulation—Able Seaman (Bosun's Mate 20), 6 hrs sleep with lapse index

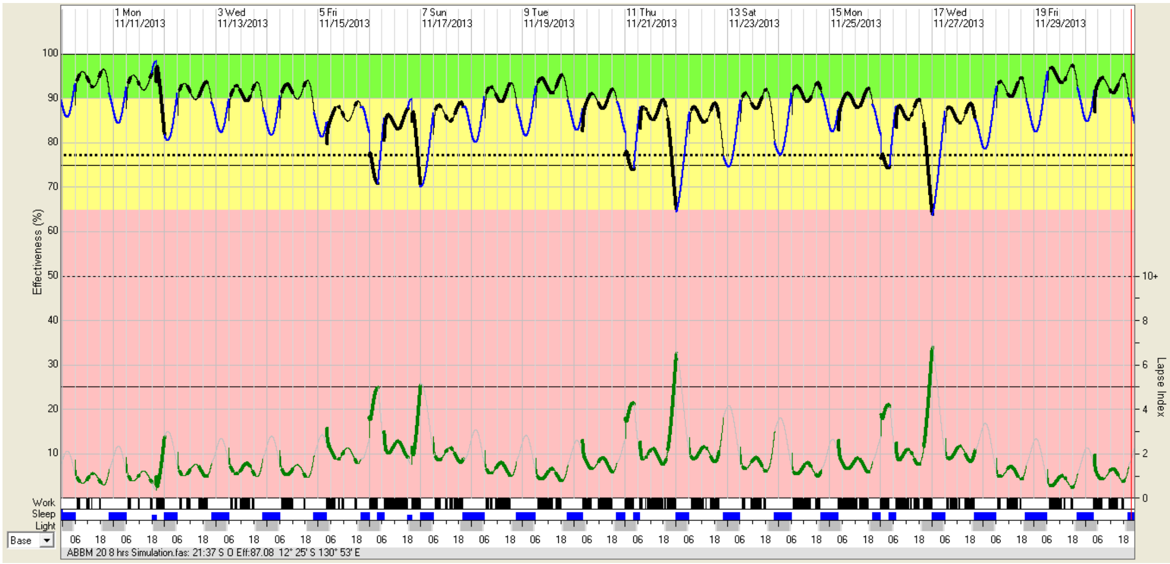


Figure 80. FAST Simulation—Able Seaman (Bosun's Mate 20), 6 hrs sleep with lapse index

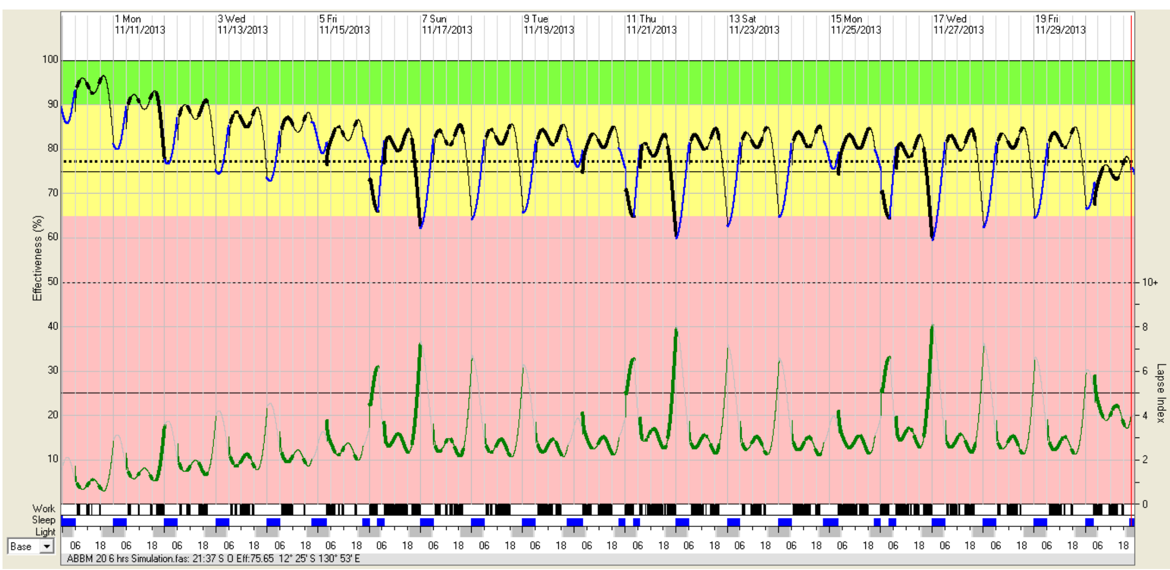


Figure 81. FAST Simulation—Leading Seaman (CIS 21), 8 hrs sleep with lapse index

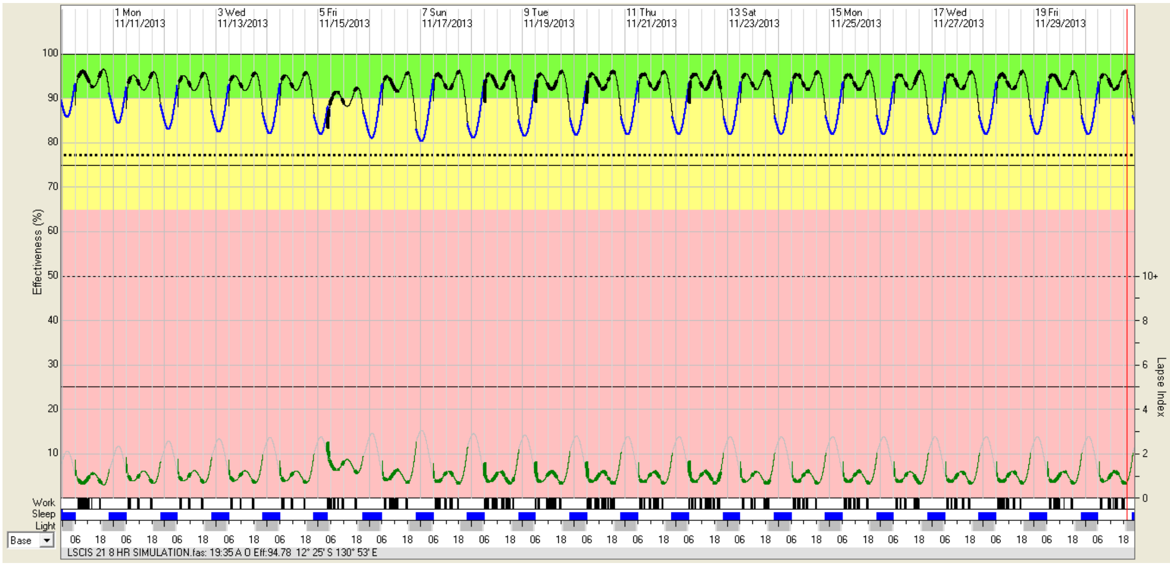
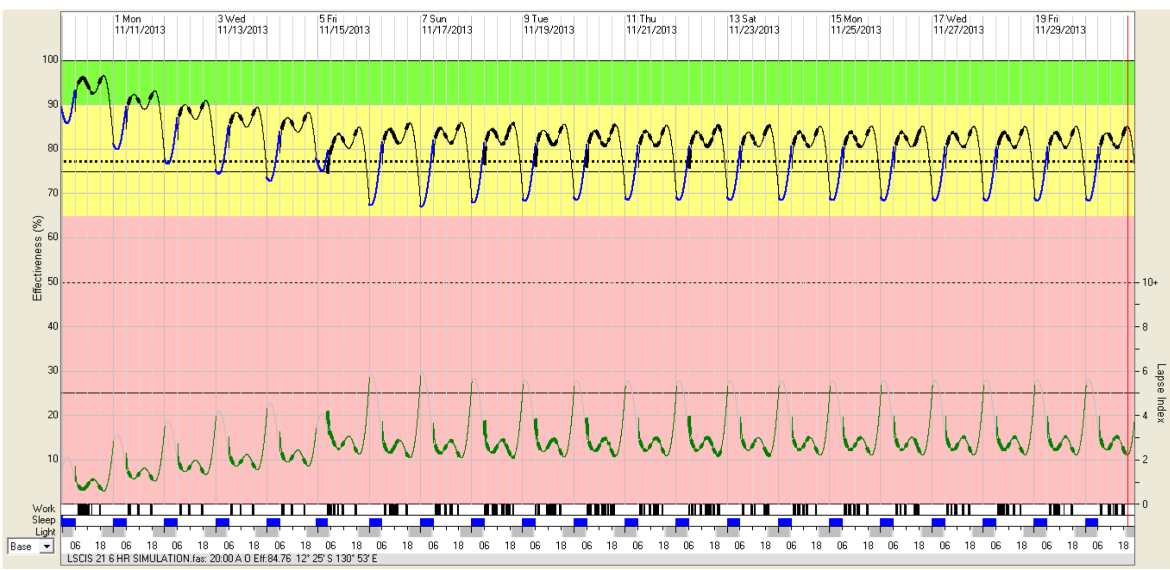


Figure 82. FAST Simulation—Leading Seaman (CIS 21), 6 hrs sleep with lapse index



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APPENDIX E. SIMULATED FAST (BAC—SELECTED CASES)

Figure 83. FAST Simulation— Navigator 6 hrs sleep with Blood Alcohol Equivalence

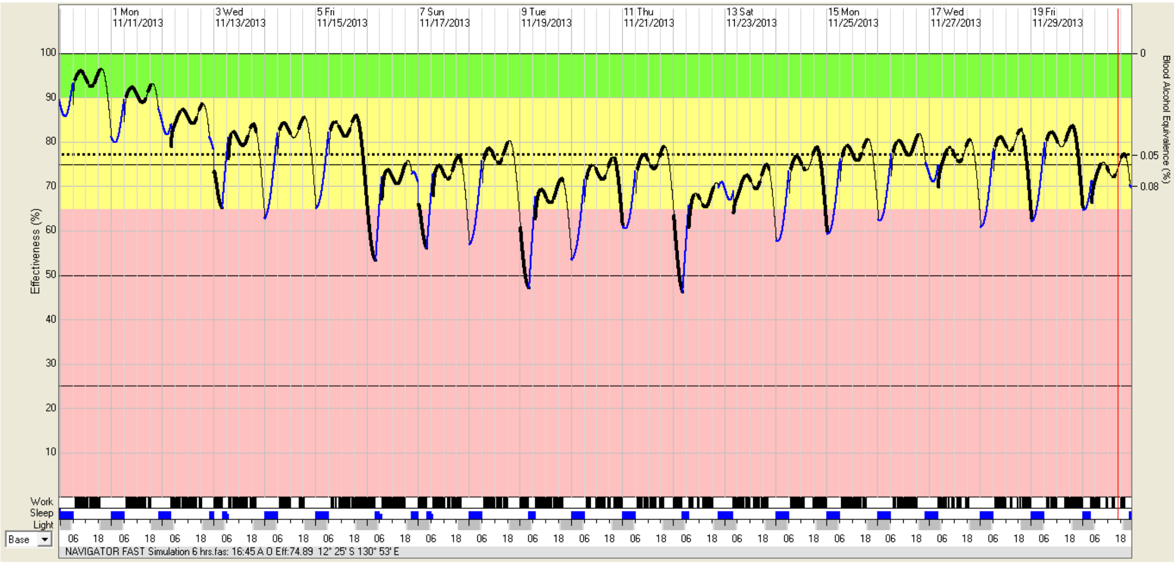


Figure 84. FAST Simulation— Able Seaman (Marine Technician 16) 6 hrs sleep with Blood Alcohol Equivalence

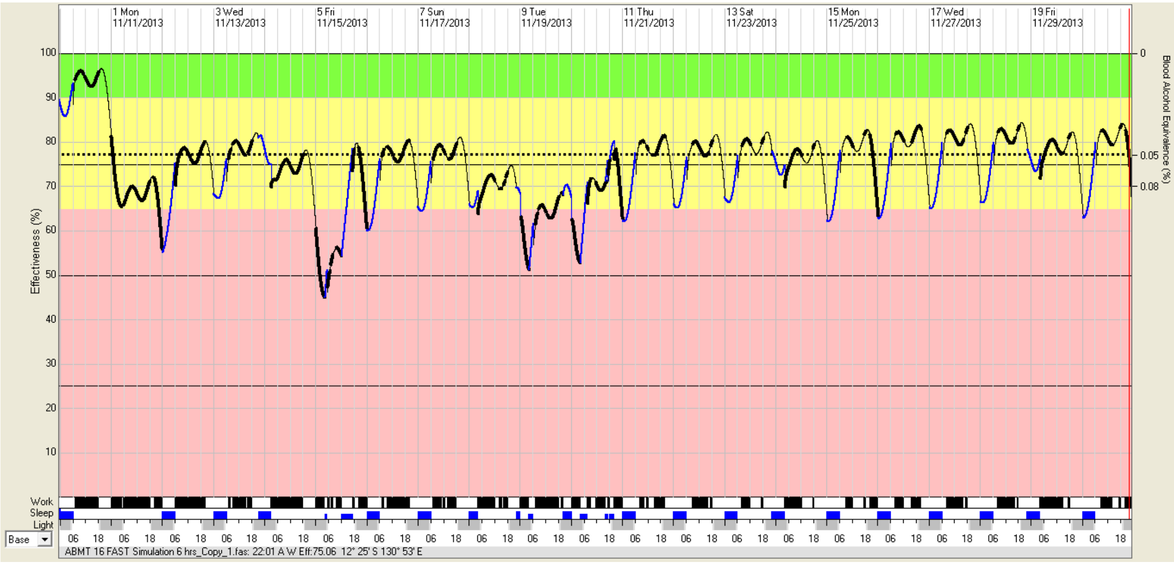


Figure 85. FAST Simulation— Commanding Officer
8 hrs sleep with Blood Alcohol Equivalence

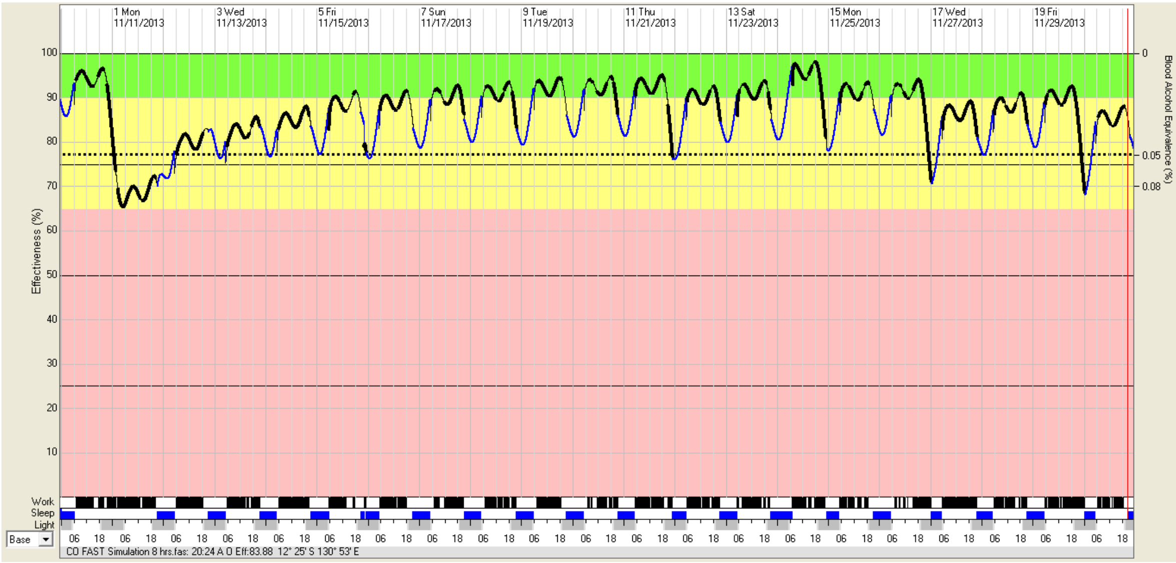


Figure 86. FAST Simulation— Commanding Officer
6 hrs sleep with Blood Alcohol Equivalence

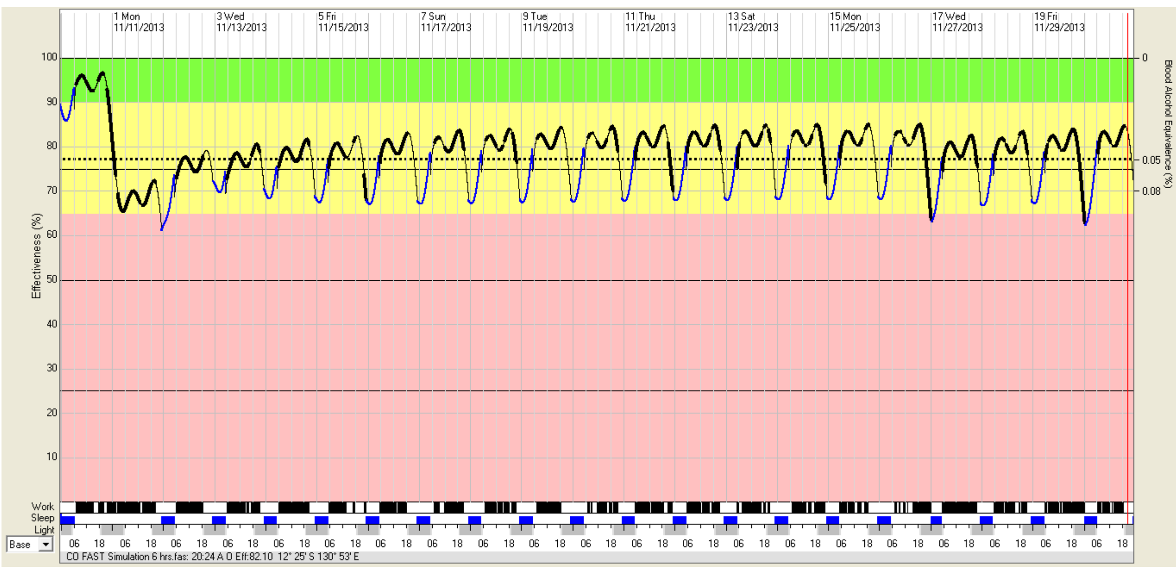
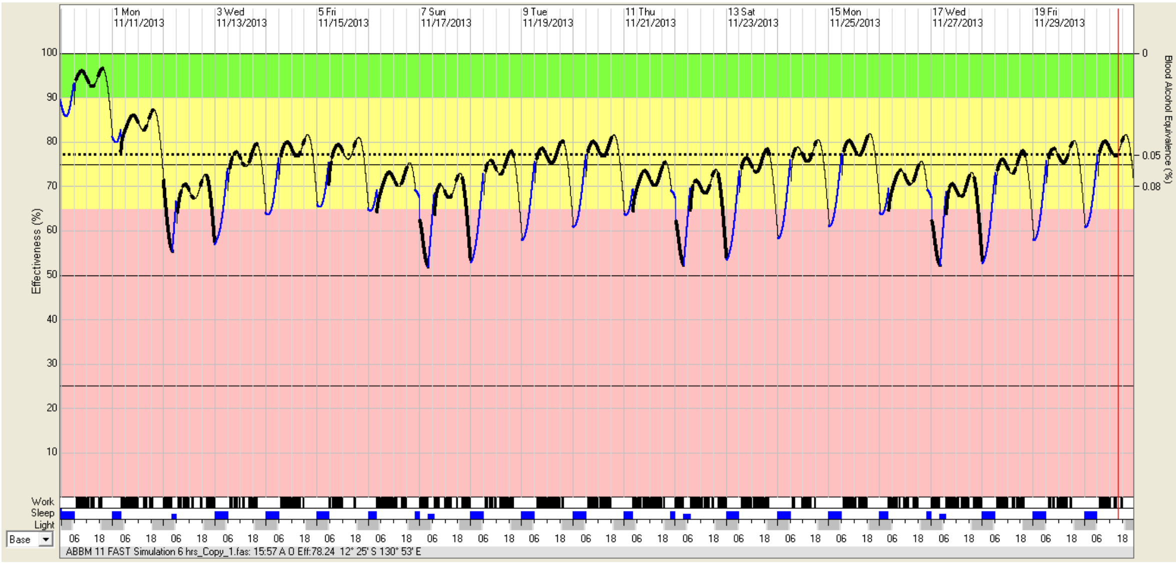


Figure 87. FAST Simulation— Able Seaman (Bosun's Mate 11)
6 hrs sleep with Blood Alcohol Equivalence



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APPENDIX F. SUMMARY TABLE OF SIMULATED ACTIVITY OF INDIVIDUAL CREW MEMBER—FAST

Table 9. FAST Summary Table – CO (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	81	21	19
Last	11/30/2013	Mean	189.3	1003.6	428.7
Average Sleep per Day	436	Median	135.0	960.0	480.0
Average Work per Day	730	SD	184.6	371.3	111.3
Average Effectiveness	86.01	Shortest	15	60	90
		Longest	975	2340	600
		Avg. Eff.	87.61	87.97	81.29

Table 10. FAST Summary Table – Executive Officer (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	105	21	19
Last	11/30/2013	Mean	145.6	1033.6	400.3
Average Sleep per Day	406	Median	120.0	1065.0	375.0
Average Work per Day	728	SD	108.8	114.9	106.0
Average Effectiveness	83.65	Shortest	15	840	240
		Longest	510	1230	600
		Avg. Eff.	85.10	85.38	79.02

Table 11. FAST Summary Table – Navigator (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	76	25	23
Last	11/30/2013	Mean	192.0	838.2	356.7
Average Sleep per Day	442	Median	150.0	960.0	420.0
Average Work per Day	695	SD	145.4	305.1	125.0
Average Effectiveness	84.77	Shortest	15	240	180
		Longest	660	1320	480
		Avg. Eff.	85.59	86.40	80.80

Table 12. FAST Summary Table – CPO (Senior Technical Officer 4) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	84	22	20
Last	11/30/2013	Mean	192.5	940.2	429.8
Average Sleep per Day	455	Median	150.0	960.0	480.0
Average Work per Day	770	SD	151.0	200.6	104.2
Average Effectiveness	88.36	Shortest	15	90	120
		Longest	1005	1110	480
		Avg. Eff.	90.86	90.75	83.03

Table 13. FAST Summary Table – PO (NPC 5) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	94	28	26
Last	11/30/2013	Mean	126.2	752.1	325.4
Average Sleep per Day	437	Median	75.0	900.0	420.0
Average Work per Day	565	SD	95.5	347.1	161.8
Average Effectiveness	84.21	Shortest	15	105	60
		Longest	345	1260	480
		Avg. Eff.	85.84	85.82	80.30

Table 14. FAST Summary Table – Petty Officer (Bosun 6) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	82	26	24
Last	11/30/2013	Mean	150.4	795.6	363.8
Average Sleep per Day	455	Median	127.5	900.0	480.0
Average Work per Day	599	SD	110.4	290.6	159.8
Average Effectiveness	87.06	Shortest	15	240	60
		Longest	525	1080	510
		Avg. Eff.	88.81	88.99	82.68

Table 15. FAST Summary Table – Leading Seaman (Bosun 7) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	86	24	22
Last	11/30/2013	Mean	170.9	847.5	403.6
Average Sleep per Day	471	Median	135.0	960.0	435.0
Average Work per Day	700	SD	136.5	288.1	158.5
Average Effectiveness	86.33	Shortest	30	240	180
		Longest	720	1440	735
		Avg. Eff.	87.23	88.05	82.52

Table 16. FAST Summary Table – Leading Seaman (Cook 8) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	67	21	19
Last	11/30/2013	Mean	182.2	960.0	481.6
Average Sleep per Day	480	Median	240.0	960.0	480.0
Average Work per Day	581	SD	111.8	0.0	12.1
Average Effectiveness	90.86	Shortest	15	960	450
		Longest	405	960	510
		Avg. Eff.	93.95	93.57	85.31

Table 17. FAST Summary Table – Leading Seaman (Electrical Technician 9) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	71	24	22
Last	11/30/2013	Mean	182.7	832.5	418.0
Average Sleep per Day	489	Median	150.0	960.0	480.0
Average Work per Day	618	SD	159.8	254.8	159.0
Average Effectiveness	88.51	Shortest	15	120	180
		Longest	720	1020	720
		Avg. Eff.	90.16	90.40	84.65

Table 18. FAST Summary Table – Able Seaman (Bosuns Mate 10) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	83	27	25
Last	11/30/2013	Mean	156.3	763.9	356.4
Average Sleep per Day	458	Median	120.0	900.0	480.0
Average Work per Day	629	SD	122.4	288.1	155.4
Average Effectiveness	86.93	Shortest	15	210	30
		Longest	570	1080	495
		Avg. Eff.	88.59	88.64	83.08

Table 19. FAST Summary Table – Able Seaman (Bosuns Mate 11) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	95	31	29
Last	11/30/2013	Mean	139.9	658.5	305.7
Average Sleep per Day	468	Median	90.0	930.0	360.0
Average Work per Day	633	SD	109.5	347.9	139.8
Average Effectiveness	85.73	Shortest	15	60	120
		Longest	480	960	480
		Avg. Eff.	86.71	87.28	82.30

Table 20. FAST Summary Table – Able Seaman (Bosuns Mate 12) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	94	28	26
Last	11/30/2013	Mean	131.2	728.6	339.2
Average Sleep per Day	469	Median	75.0	892.5	420.0
Average Work per Day	587	SD	107.4	323.7	157.3
Average Effectiveness	87.00	Shortest	15	75	60
		Longest	585	1080	480
		Avg. Eff.	88.12	88.79	83.13

Table 21. FAST Summary Table – Able Seaman (CIS 13) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	116	22	20
Last	11/30/2013	Mean	68.3	917.0	456.0
Average Sleep per Day	479	Median	60.0	960.0	480.0
Average Work per Day	377	SD	55.8	147.2	83.5
Average Effectiveness	90.12	Shortest	15	405	120
		Longest	330	1050	480
		Avg. Eff.	93.07	92.60	85.07

Table 22. FAST Summary Table – Able Seaman (Marine Technician 14) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	68	26	24
Last	11/30/2013	Mean	223.7	781.2	379.4
Average Sleep per Day	473	Median	195.0	900.0	420.0
Average Work per Day	724	SD	179.3	296.5	162.8
Average Effectiveness	86.84	Shortest	15	60	60
		Longest	720	1080	720
		Avg. Eff.	87.97	88.42	83.47

Table 23. FAST Summary Table – Able Seaman (Electrical Technician 15) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	83	26	24
Last	11/30/2013	Mean	144.2	778.3	376.9
Average Sleep per Day	476	Median	75.0	952.5	480.0
Average Work per Day	570	SD	131.7	312.5	145.0
Average Effectiveness	88.09	Shortest	30	75	60
		Longest	780	1080	600
		Avg. Eff.	89.54	90.04	84.02

Table 24. FAST Summary Table – Able Seaman (Marine Technician 16) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	73	26	24
Last	11/30/2013	Mean	180.8	807.7	355.0
Average Sleep per Day	440	Median	150.0	900.0	450.0
Average Work per Day	640	SD	150.0	335.1	152.1
Average Effectiveness	83.91	Shortest	15	45	60
		Longest	840	1440	480
		Avg. Eff.	84.75	85.17	80.78

Table 25. FAST Summary Table – Able Seaman (Cook 17) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	90	21	19
Last	11/30/2013	Mean	131.0	960.0	480.0
Average Sleep per Day	480	Median	90.0	960.0	480.0
Average Work per Day	561	SD	103.2	0.0	0.0
Average Effectiveness	90.42	Shortest	15	960	480
		Longest	420	960	480
		Avg. Eff.	93.80	93.05	85.12

Table 26. FAST Summary Table – Able Seaman (Electrical Technician 18) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	72	22	20
Last	11/30/2013	Mean	182.9	948.4	420.8
Average Sleep per Day	446	Median	112.5	960.0	480.0
Average Work per Day	627	SD	165.3	189.1	100.1
Average Effectiveness	86.86	Shortest	15	255	150
		Longest	600	1440	480
		Avg. Eff.	88.29	88.89	82.15

Table 27. FAST Summary Table – Leading Seaman (Bosun 19) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	86	26	24
Last	11/30/2013	Mean	134.8	777.7	371.3
Average Sleep per Day	477	Median	60.0	862.5	360.0
Average Work per Day	552	SD	121.9	291.6	160.8
Average Effectiveness	88.33	Shortest	15	60	150
		Longest	600	1035	645
		Avg. Eff.	89.12	90.11	84.75

Table 28. FAST Summary Table – Able Seaman (Bosun's Mate 20) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	85	26	24
Last	11/30/2013	Mean	134.3	777.7	372.5
Average Sleep per Day	477	Median	75.0	930.0	390.0
Average Work per Day	544	SD	103.0	280.1	154.2
Average Effectiveness	87.42	Shortest	15	240	120
		Longest	330	1020	600
		Avg. Eff.	88.12	89.26	83.50

Table 29. FAST Summary Table – Leading Seaman (CIS 21) (8hrs) Average Effort

Entire schedule		Intervals			
Total Days	21		Work	Wake	Sleep
First	11/10/2013	N	97	21	19
Last	11/30/2013	Mean	63.2	961.4	478.4
Average Sleep per Day	479	Median	45.0	960.0	480.0
Average Work per Day	292	SD	47.8	6.5	25.4
Average Effectiveness	90.74	Shortest	15	960	390
		Longest	300	990	540
		Avg. Eff.	94.02	93.44	85.24

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APPENDIX G. SUMMARY TABLE OF SIMULATED AVAILABLE, PRODUCTIVE AND NON-AVAILABLE TIME

CREW MEMBER	ID	AVAILABLE TIME	NON-AVAILABLE TIME	PRODUCTIVE TIME	TOTAL
CO	1	16.42	100.50	51.08	168.00
XO	2	26.42	99.75	41.83	168.00
NAV	3	11.83	98.92	57.25	168.00
CPO	4	13.50	96.08	58.42	168.00
ABMT	14	9.67	97.17	61.17	168.00
LSBM	7	13.25	98.25	56.50	168.00
LSCK	8	5.67	118.75	43.58	168.00
ABBM	10	15.33	107.50	45.17	168.00
ABBM	11	16.83	108.08	43.08	168.00
ABBM	12	14.42	112.83	40.75	168.00
ABCIS	13	13.50	141.00	13.50	168.00
ABET	15	7.58	116.08	44.33	168.00
LSET	9	9.75	109.92	48.33	168.00
ABMT	16	7.75	105.08	55.17	168.00
POB	6	12.08	112.00	43.92	168.00
PONPC	5	10.75	115.17	42.08	168.00
ABCK	17	5.75	119.83	42.42	168.00
ABET	18	4.33	111.75	51.92	168.00
LSB	19	7.75	117.42	42.83	168.00
ABBM	20	10.17	118.67	39.17	168.00
LSCIS	21	6.33	150.33	11.33	168.00

Available time = training + meeting

Non-available time = sleep + messing + personal

Productive time = maintenance + watch

Total time = NSWW 168 hours

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